Chas. D. Walcott.

FIFTEENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1893-94

BY

J. W. POWELL
DIRECTOR

WASHINGTON
GOVERNMENT PRINTING OFFICE
1895

FIFTEENTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY.

1893-94.

CONTENTS.

REPORT OF THE DIRECTOR.

ADMINISTRATIVE REPORTS.

ACCOMPANYING PAPERS.

PRELIMINARY REPORT ON THE GEOLOGY OF THE COMMON ROADS OF THE UNITED STATES, BY NATHANIEL SOUTHGATE SHALER.

THE POTOMAC FORMATION, BY LESTER FRANK WARD.

SKETCH OF THE GEOLOGY OF THE SAN FRANCISCO PENINSULA, BY ANDREW C. LAWSON.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

Department of the Interior,
U. S. Geological Survey,
Washington, D. C., June 30, 1894.

Sir: I have the honor to transmit herewith a report of the operations of the Geological Survey for the year ending to-day.

With great respect, I am your obedient servant,

J. W. Powell,
Director.

Hon. Hoke Smith,
Secretary of the Interior.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY

REPORT

OF THE

DIRECTOR

FOR THE

FISCAL YEAR ENDING JUNE 30, 1894.

CONTENTS.

REPORT OF THE DIRECTOR.

ADMINISTRATIVE REPORTS.

ILLUSTRATION

TO MY COLLABORATORS.

On this day my resignation as Director of the Geological Survey takes effect. Under different organizations I have had charge of the work for twenty-five years. In the beginning it was largely exploratory, but gradually, as the Survey expanded, it became more and more administrative, affording less time for research. The changes made in the personnel of the Survey have not been great, but steadily the scientific corps has been enlarged. Some of my old associates have been called to more responsible positions; the others who are living are still with me, and they have sacrificed the advantages of promotion that they might give their energies wholly to original research. In this severance of our relations, made necessary by painful disability, I can not refrain from an expression of profound gratitude for the loyal and loving aid which they have given me, ever working together with zeal and wisdom to add to the sum of human knowledge. The roster of these honored men is found in ten-score volumes of contributions to knowledge and fifty-score maps familiar to the scholars of the world, and their names need no repetition here. And yet there are five who must have special mention from the fact that their relations to myself were most intimate.

Mr. James Stevenson, my first executive officer, is dead, but the memory of his fidelity is green.

Mr. James C. Pilling, first my stenographer, then chief clerk, and finally associate in scientific work, will too soon retire with the laurels of scholarly achievement.

Mr. A. H. Thompson was my companion in youth and my first associate in exploration, and his courage was my support in the solitude.

Mr. Grove Karl Gilbert, my companion in early studies, my associate for many years, and chief geologist for a lengthened term, has ever been my wise adviser.

Mr. Chas. D. Walcott, my friend, my collaborator, and the chief geologist of the Survey for the past two years, remains as its able Director.

And still another must be mentioned. Mr. J. K. Hillers was with me in the wilderness life of early years, and gave me aid in stemming the river torrents; as a gatherer of the sun-painted scenes of the Western World he has enriched the publications of the Survey.

May the achievements of the past be crowned with the higher achievements of the future!

With feelings of deep endearment, I say good-bye.

J. W. POWELL.

WASHINGTON, *June 30, 1894.*

FIFTEENTH ANNUAL REPORT OF THE UNITED STATES GEOLOGICAL SURVEY.

BY J W POWELL, DIRECTOR.

PLAN OF WORK FOR THE FISCAL YEAR 1893-'94.

The work of the Geological Survey is performed under the direction of the Secretary of the Interior. At the beginning of each fiscal year a plan of operations for such year is prepared by the Director and laid before the Secretary. This, if approved by him, becomes in effect the general order for the year's work.

The plan of operations for the fiscal year 1893–'94 was submitted by the Director to the honorable the Secretary of the Interior, May 4, 1893, and was approved by him June 16, 1893. The following is that plan as approved, in accordance with which the work covered by this report was performed:

APPROPRIATIONS.

The sundry civil appropriations act for the fiscal year 1893–'94 appropriates for the work of the U. S. Geological Survey the sum of $414,100. Separate amounts are by the terms of the act set apart for specific branches of work and for the salaries of persons connected with these branches. For convenience of reference these separate appropriations are here brought together and classified as follows:

For pay of skilled laborers, etc		$13,000
For topographic surveys	$200,000	
For pay of 2 geographers and 2 topographers	9,200	
Total appropriation for topographic work		209,200
For geological surveys	70,000	
For pay of 4 geologists	13,700	
Total appropriation for geologic work		83,700
For paleontologic researches	10,000	
For pay of two paleontologists	4,000	
Total for paleontologic work		14,000
For chemical and physical researches	5,000	
For pay of one chemist	3,000	
Total for chemical work		8,000
For preparation of illustrations		13,000
For preparation of report on mineral resources		12,000
For purchase of books and distribution of documents		2,000
For engraving and printing maps		55,000
For rent		4,200
Total		414,100

Furthermore, there is appropriated in the same act for engraving, printing, and binding publications of the Geological Survey $35,000, this sum to be disbursed, not by the Geological Survey, but by the Public Printer.

The items are as follows:

For engraving illustrations for report of Director	$5,000
For engraving illustrations for monographs and bulletins	10,000
For printing and binding monographs and bulletins	20,000
Total	35,000

Lastly, the legislative, executive, and judicial appropriations act for 1893-'94 appropriates for the Geological Survey $45,540, in two items, as follows·

For salaries of Director, executive officer, chief clerk, chief disbursing clerk, librarian, and photographer, together with clerks, messengers, watchmen, and others, to the number of 30 persons in all	$35,540
For rent	10,000
Total	45,540

Thus the aggregate appropriation for the Geological Survey for the fiscal year 1893-'94 is $494,640.

TOPOGRAPHY.

The amount appropriated for topographic work is $200,000. By the terms of the law it is provided—

First, That $60,000 shall be expended for topographic work west of the ninety-seventh meridian in the States of North Dakota, South Dakota, Nebraska, Kansas, and Texas, and the territory of Oklahoma.

Second, That at least $70,000 shall be expended for topographic work west of the one hundred and third meridian.

Third, That $70,000 may be expended for work east of the ninety-seventh meridian.

It is proposed that the work east of the ninety-seventh meridian shall continue, as heretofore, under the direction of Mr. Henry Gannett; that all work west of the one hundred and third meridian shall continue, as heretofore, under the direction of Mr. A. H. Thompson; and that of the $60,000 appropriated for work in the two Dakotas, Nebraska, Kansas, Texas, and Oklahoma, one-half shall be expended for work under the direction of Mr. Henry Gannett, and one-half under the direction of Mr. A. H. Thompson, as heretofore. Thus there will be allotted for the work of the Eastern Division, under Mr. Gannett's direction, $100,000, two sets of accounts to be kept, one of $70,000 and one of $30,000; and for the Western Division, under Mr. Thompson's direction, $100,000, two sets of accounts to be kept, one of $70,000 and one of $30,000.

In addition to these sums there is appropriated for the salaries of a chief geographer, one geographer, and two topographers, an aggregate sum of $9,200. Three of the persons to whom these stated salaries are to be paid, aggregating $7,200, are assigned to the Eastern Division, and one, with a salary of $2,000, to the Western Division. Thus the total allotment for the Eastern Division for all expenses in field and office will be $107,200, and for the Western Division $102,000.

Herewith is transmitted a map of the United States on which areas already mapped are shown by a blue tint, and those which it is proposed to survey during the coming year by a pink tint. The distribution of the appropriation for topography, in three grand divisions, Eastern, Central, and Western, in accordance with the law, is also shown on this map. The Eastern Division comprises the area east of the ninety-seventh meridian; the Western Division, that lying west of the one hundred and third meridian; and the Central Division, an area lying for the most part between these two.

The following abstract of allotments is followed by a detailed explanation of work contemplated:

Abstract of allotments for topography for 1893-'94.

I.—EASTERN DIVISION.

State, etc.	Parties	Eastern.	Middle	Western.	Total.
Northeastern section:					
New York	10 parties	$25,000			$25,000
Vermont	1 party	5,000			5,000
New Hampshire	1 party	5,000			5,000
Southeastern section:					
Tennessee	1 party	5,000			5,000
West Virginia	1 party	5,000			5,000
North Carolina	1 party	5,000			5,000
Central section.					
Minnesota	1 party	5,000			5,000
North Dakota	1 party		$5.000		5,000
South Dakota	1 party		5,000		5,000
Nebraska	2 parties		12,000		12,000
Kansas	1 party		2,000		2,000
Oklahoma	1 party		6,000		6,000
Administration, disbursement, office force, etc.		15,000			15,000
Unallotted		7,200			7,200
Total		77,200	30,000		107,200

Abstract of allotments for topography for 1893-'94—Continued.

II.—WESTERN DIVISION.

State, etc.	Parties.	Eastern.	Middle.	Western.	Total.
California	5 parties			$22,500	$22,500
Colorado	2 parties			8,000	8,000
Idaho	1 party			5,000	5,000
Oregon	2 parties			6,000	6,000
South Dakota	2 parties		$7,000		7,000
Texas	3 parties		15,000		15,000
Washington	1 party			4,500	4,500
Wyoming	2 parties			8,000	8,000
Stream gaging			1,000	3,000	4,000
Administration, disbursement, office force, etc.			5,000	10,000	15,000
Unallotted			2,000	5,000	7,000
Total			30,000	72,000	102,000

PLANS FOR TOPOGRAPHIC WORK OF THE EASTERN DIVISION, UNDER THE DIRECTION OF MR. HENRY GANNETT.

This work has heretofore been organized in three sections: the northeastern, in charge of Mr. H. M. Wilson; the southeastern, in charge of Mr. Gilbert Thompson; and the central, in charge of Mr. J. H. Renshawe. It is proposed to continue this plan of organization.

New York.—The State of New York has recently appropriated $24,000 for cooperation with the U. S. Geological Survey in topographic work, and has made this appropriation immediately available. It is accordingly proposed to commence work in that State upon an extensive scale on the first of May and, throughout the season, to employ one party for primary triangulation and nine parties for topography. The triangulation party will first execute such work as is needful for controlling areas to be surveyed during the coming season, and will then be occupied in extending triangulation for future work. The topographic parties will survey the following areas:

A Two sheets on the northern boundary of the State westward from Lake Champlain.

B. Three sheets in the Adirondack region westward from Lake Champlain.

C. Complete the Salem sheet and the two sheets north of it.

D. Complete the two sheets remaining in the valley of the Hudson east of the Catskills.

E. Five sheets upon the east shore of Lake Ontario, in the neighborhood of Watertown.

F. The two sheets which include Oneida Lake.

G. The Ithaca and Elmira sheets.

H. The Buffalo and Niagara Falls sheets and the sheet east of the latter.

This makes a total of twenty-two sheets to be surveyed, either wholly or in part, and for this it is proposed to allot $25,000.

Vermont.—On the first of July it is proposed to put a party in southwestern Vermont to survey two sheets lying west and southwest of Rutland. The allotment recommended for this work is $5,000.

New Hampshire.—At the same time it is proposed to put a party in New Hampshire to continue southward the survey of the White Mountain region. The allotment recommended for this work is $5,000.

Tennessee.—One party will work in Tennessee and survey the two sheets west of the Briceville sheet. Proposed allotment for this work, $5,000.

West Virginia.—Two parties will work in West Virginia and revise the Tazewell and Grundy sheets. Proposed allotment for this work, $5,000.

North Carolina.—One party will complete certain partially surveyed sheets in North Carolina; another will complete the revision of the Nantahala sheet, and if possible will revise the Cowee sheet, in the mountain region of North Carolina. Proposed allotment for this work, $5,000.

Minnesota.—The Mesabi Range of Minnesota is a region of growing economic importance, and it is accordingly proposed to begin work there with one party and prosecute it as far as possible. For this work is recommended an allotment of $5,000.

North Dakota.—One party will continue work in the James River valley and the hill country to the westward. Proposed allotment, $5,000.

South Dakota.—One party will continue the survey of the James River valley. Proposed allotment, $5,000.

Nebraska.—Two parties will work in the valley of the Platte River, one to the north and one to the south of the river. Proposed allotment, $12,000.

Kansas.—One party will complete the survey of that part of the State lying east of the one-hundredth meridian. Proposed allotment, $2,000.

Oklahoma.—One party will complete the survey of the original territory. Proposed allotment, $6,000.

For the expenses of administration, supervision, disbursement, and for clerical and office forces, it is recommended that there be allotted $15,000, leaving unallotted for unforeseen and contingent expenses the sum of $7,200.

The amounts thus recommended are to be taken as tentative and subject to more or less important changes as need therefor shall appear. It is believed, however, that they are sufficiently ample to leave a balance for some winter work and for renewing field work next spring as soon as the weather shall permit.

PLANS FOR TOPOGRAPHIC WORK OF THE WESTERN DIVISION, UNDER THE DIRECTION OF MR. A. H. THOMPSON

It is proposed to carry on topographic work in eight States, as follows:

California.—Five parties will be employed in three districts, two to continue the work in the Gold Belt region, one to complete the atlas sheets in the vicinity of San Francisco, and two to continue work in the vicinity of Los Angeles and San Bernardino. The allotment proposed for this work is $22,500.

Colorado.—It is proposed to employ two parties to continue the detailed surveys of the Aspen mining district and to extend work northward from the Crested Butte and Anthracite atlas sheets, and for this work to allot $8,000.

Idaho.—It is proposed to employ one party to complete the Idaho Basin atlas sheet, to survey the Weiser sheet, and to extend triangulation into the unmapped area, and for this work to allot $5,000.

Oregon.—It is proposed to employ two parties to complete the Grant Pass atlas sheet and to extend the work northward from the present surveyed area about Roseburg, and to allot for this work $6,000.

South Dakota.—It is proposed to continue with two parties the surveys in the Black Hills region and, if possible, to complete the Hill City sheet, allotting for this purpose $7,000.

Texas.—It is proposed to carry on work with three parties in two localities, one in the Rio Grande valley south of the thirty-first parallel and between the one hundred and third and one hundred and sixth meridians, and the other between the thirty-first and thirty-third parallels, west of the present surveyed area. Proposed allotment for this work, $15,000.

Washington.—It is recommended that one party be employed in mapping in the vicinity of Seattle, and that for it there be allotted $4,500.

Wyoming.—Work is proposed to be done in two localities: first, in the forest reservation east of Yellowstone Park, and second, westward from Laramie, adjoining work previously done. Allotment recommended for this work, $8,000.

In addition to the foregoing, it is proposed to continue in a small way the gaging of streams hitherto carried on, and to allot therefor the sum of $4,000.

For expenses of administration, supervision, and disbursement, and for clerical and office force, it is recommended that there be allotted $15,000, leaving unallotted for unforeseen and contingent expenses the sum of $7,000.

GEOLOGY.

The total appropriation for geologic work for 1893–'94 is $83,700, as shown on page 10 of this report. The following abstract of proposed allotment for the different sections of work is followed by a detailed explanation of the plans:

Parties.	Allotments.
Executive office of geologist in charge	$8,800
N. S. Shaler (Massachusetts)	2,500
B. K. Emerson (Massachusetts)	500
T. N. Dale (New York and Vermont)	2,500
J. E. Wolff (New Jersey)	500
G. H. Williams (northeastern Maryland)	500
M. R. Campbell (Virginia)	3,000
A. Keith (Tennessee)	3,100
C. W. Hayes (Georgia, Alabama, and Tennessee)	3,300
W. B. Clark (Eastern Maryland and New Jersey)	400
G. H. Eldridge (Florida)	3,700
C. R. Van Hise (Lake Superior)	7,000
G. K. Gilbert (Colorado and New Mexico)	8,400
T. C. Chamberlin (Illinois)	2,250
C. R. Prosser (Kansas)	400
A. Hague (Wyoming)	5,600
J. P. Iddings (Wyoming)	1,400
W. H. Weed (Montana)	3,200
G. H. Eldridge (Wyoming)	1,000
C. W. Cross (Colorado)	5,300
J. S. Diller (Oregon and northern California)	6,600
B. Willis (Washington)	4,700
H. W. Turner (California)	3,400
W. Lindgren (California)	2,800
A. C. Lawson (California)	400
Unallotted	2,450
Total	83,700

EXECUTIVE OFFICE, ETC.

It is recommended that for the salary and expenses of the geologist in charge of geology and paleontology, Mr. C. D. Walcott, for the salary and expenses of Mr. C. D. Davis, assistant geologist and special disbursing agent, and for the salary of Mr. W. F. Morsell, clerk to the geologist in charge and general clerk of the Division of Geology, there be allotted the sum of $8,800

NEW ENGLAND DIVISION

This region covers the New England States, the Adirondack Mountains, and the counties east of the Hudson in New York It is proposed that three parties carry on work in this field, as follows

Shaler party—This party will continue the mapping of the Pleistocene geology in the States of Connecticut and Maine, and office work on the Pleistocene maps of New England This work will be in charge of Prof N. S Shaler, who will employ temporary assistants, and it is recommended that there be allotted for it the sum of $2,500.

Emerson party—It is proposed that Prof B. K Emerson remain in charge of, and with his temporary assistants continue the mapping of the areal geology of western Massachusetts and northern Connecticut, and that for the work there be allotted the sum of $500

Dale party—It is proposed that Prof T N Dale complete geologic sections on the Pittsfield and Berlin sheets of western Massachusetts and eastern New York and finish mapping the Troy sheet of New York, and that for this work there be allotted the sum of $2,500

APPALACHIAN REGION.

This region embraces the Appalachian Mountain system between the Hudson River on the north and central Alabama on the south, and it is proposed that five parties continue the mapping of its areal geology, as follows:

Wolff party—This party, in charge of Mr J E Wolff, will make a special study of the Archean rocks of northern New Jersey This work will be done in cooperation with the Geological Survey of New Jersey, in continuation of an agreement to map the ancient crystalline and metamorphic rocks of the State, or those containing deposits of iron and zinc The State survey is to map the surface formations, and the results jointly obtained by the two organizations are to be treated as the common property of both.

It is recommended that this organization be continued, and that for its work there be allotted the sum of $500.

Williams party.—It is proposed to continue the investigation and mapping of the older crystalline rocks of central and northern Maryland, and to cooperate with the State geologist of North Carolina for similar work in certain areas of western North Carolina, the whole to be in charge of Dr. George H. Williams, of Johns Hopkins University, who can give attention to it for a portion of the year, and for all this work to allot the sum of $500.

Campbell party.—It is proposed in the central Appalachian region to continue the mapping of formations carrying coal and iron deposits in southwestern Virginia, the work to be in charge of Mr. M. R. Campbell, assisted during part of the field season by Mr. David White, assistant paleontologist. For this work it is recommended that there be allotted $3,000.

Keith party.—It is proposed that the party in charge of Mr. Arthur Keith shall complete the mapping of the Roan Mountain, Nantahalah, and Murphy sheets of western North Carolina and eastern Tennessee, shall survey the Briceville sheet of eastern Tennessee, assisted by Mr. David White, assistant paleontologist, and that for all this work there be allotted the sum of $3,100.

Hayes party.—It is proposed that the party in charge of Mr. C. W. Hayes, in continuation of work by him in northwestern Georgia and northeastern Alàbama, shall complete the Dalton and Rome sheets of Georgia, the Fort Payne sheet of Alabama, and shall survey the Sewanee sheet of eastern Tennessee. For this work is recommended an allotment of $3,300.

ATLANTIC AND GULF COASTAL PLAIN.

Under this phrase is embraced the Coastal Plain area from the mouth of the Hudson to the mouth of the Rio Grande, and it is proposed that two parties be engaged in the study and mapping of its geologic formations.

Clark party.—It is proposed that this party, in charge of Prof. William B. Clark, of Johns Hopkins University, shall continue to study and map the geologic formations of eastern Maryland and New Jersey, and that for it there be allotted the sum of $400.

Eldridge party.—It is proposed that the study and mapping of the mineral phosphate deposits in Florida, and their geological relations, shall continue in charge of Mr. George H. Eldridge, and that for this work there be allotted the sum of $3,700.

INTERIOR OR MISSISSIPPI REGION.

This region includes the area east of the Rocky Mountains, west of the Appalachian province, and north of the Gulf Coastal Plain. It is proposed that four parties shall work within it, as follows:

Van Hise party.—For several years Prof. C. R. Van Hise has been studying and mapping the formations of the Lake Superior region, formations on which its great mining industries are founded. It is proposed that he shall continue this work, especially in the Marquette and Michigamme districts, and that for it there be allotted the sum of $7,000.

Gilbert party.—The region of the Great Plains east of the Rocky Mountains is one of scientific interest and economic importance. It is proposed to begin an investigation of its geology, in connection with the artesian water supply, the work to be in charge of Mr. G. K. Gilbert, assisted by Mr. N. H Darton. Work will begin with the study and areal mapping of the formations east and south of Denver, Colo. For this work is recommended an allotment of $8,400.

Chamberlin party.—This party has for several years been studying the superficial formations from which the soils of the Northern States are derived. It is recommended that this work be continued in charge of Dr. T. C. Chamberlin, of the University of Chicago, who will give what time is necessary to supervising the work, and will be assisted by Mr. Frank Leverett and Mr. J. A. Udden. Its field of work will be the northern part of the interior region. It is recommended that there be allotted for this work the sum of $2,250.

Prosser party—It is proposed that the mapping of the coal-bearing formations of eastern Kansas be begun by Prof. C. R. Prosser, of Washburn College. To this work he can give a part of his time, and will begin during the summer. For it is recommended an allotment of $400.

ROCKY MOUNTAIN REGION.

This region includes the area of the Rocky Mountains between the British and Mexican boundaries. It is proposed that work be carried forward in it by five parties, as follows:

Hague party.—The work of this party includes the preparation of a descriptive account of the geology of the Yellowstone National Park, in connection with which it is desirable that further study be made of several points within the park. For this work, in charge of Mr. Arnold Hague, it is recommended that there be allotted the sum of $5,600.

Iddings party.—In view of the setting aside of a forest reservation east of the Yellowstone National Park, and the need for more information respecting its resources, it is proposed that Mr. J P Iddings be assigned to examine and report upon it, and that for the work there be allotted the sum of $1,400.

Weed party.—It is proposed that a party in charge of Mr. W. H. Weed shall complete the mapping of the Little Belt Mountain area in central Montana, and shall make a reconnoissance of the coal fields of northern-central Montana, and that for this work there be allotted $3,200.

Eldridge party.—Before Mr. George H Eldridge begins the proposed work in Florida it is recommended that he reconnoiter the coal-bearing rocks of the Big Horn basin of Wyoming to determine their extent and character. For this task he is well qualified from studies already made in the region north of this basin. It is recommended for this work that there be allotted the sum of $1,000.

Cross party.—A topographic map of the region including the Cripple Creek mining area of Colorado has been completed. It is proposed that Mr. Whitman Cross shall map the geology of the Pike's Peak sheet, with special reference to the distribution of the metalliferous rocks, and that for this work there be allotted the sum of $5,300.

PACIFIC REGION.

In this region, which includes the Pacific coast, the Columbian mesas of Washington, Oregon, and Idaho, and the Great Basin area of Nevada, Utah, and Arizona, it is proposed that field work be carried on by five parties, as follows:

Diller party.—Mr. J. S. Diller has been occupied for several years in mapping the areal geology of northern California and southwestern Oregon, and it is proposed that he continue this work. He has also for several years had charge of the petrographic laboratory, and this arrangement it is proposed to continue. In this laboratory thin sections of rocks are made for microscopic study; by it are collected typical rocks for distribution to educational institutions; and to it are referred various questions on the constitution and nomenclature of rocks. In this work Mr. Diller is assisted by Messrs. E. G. Paul and F. C. Ohm.

It is recommended that there be allotted for the work of Mr. Diller in California and Oregon $4,500, and for the salaries of assistants and for running expenses of the petrographic laboratory the sum of $2,100, making a total of $6,600.

Willis party.—The proposed work of this party, in charge of Mr. Bailey Willis, is an investigation of the coal-bearing rocks of central Washington eastward from the meridian of Seattle. This will consist of and include a study of the geologic structure and geographic distribution of the rocks and their contained coal beds. For this work is recommended an allotment of $4,700.

Turner party.—Mr. H. W. Turner has partially completed the geologic mapping of the Downieville and Bidwell Bar sheets, in the Gold Belt of California. It is proposed that he complete the Downieville sheet and, if possible, the Bidwell Bar sheet, and that for this work there be allotted the sum of $3,400.

Lindgren party.—It is proposed that Mr. W. Lindgren complete the Truckee sheet of the Gold Belt in California, and also make a detailed survey of the Nevada City and Grass Valley mining districts of the Nevada City sheet, a special topographic map having been made for this purpose. It is recommended that there be allotted for this work the sum of $2,800.

Lawson party.—Dr. Andrew C. Lawson, of the University of California, has been engaged heretofore upon the survey of the Coast Range of California south of San Francisco. It is recommended that this work be continued, and that for it there be allotted the sum of $400.

PALEONTOLOGY.

The total appropriation for the paleontologic work is $14,000, as shown on page 10. The following abstract of its proposed allotments is followed by a detailed explanation of the plans proposed:

Divisions.	Allotments	Divisions.	Allotments.
Paleozoic	$1,500	General assistants	$1,200
Mesozoic	1,700	Unallotted	900
Cenozoic	2,900		
Paleobotany	3,800	Total for paleontologic work	$14,000
Vertebrate paleontology	2,000		

ORGANIZATION.

It is proposed that the Paleontologic Division of the Survey shall continue its work of identifying and correlating geologic formations by the study of their contained organic remains. The object of such study is to increase and improve our knowledge of the occurrence and distribution of faunas and floras, and to aid the geologist in delineating areal geology and in making geologic maps. The members of the division will, in addition to their regular office work, make certain studies in the field, such studies to be made either independently or in connection with the work of one of the geologic parties.

PALEOZOIC.

The work upon Paleozoic invertebrates will be almost wholly confined to the study and identification of fossils in the laboratory. This work will be in charge of an assistant. For it is recommended an allotment of $1,500.

MESOZOIC.

In this field it is proposed that Mr. T. W. Stanton be associated with the geologic parties in central and northern California for the purpose of obtaining paleontologic data by which to correlate the geologic formations of the Gold Belt. On his return from the field he will be employed in studying the material collected in connection with that already obtained from other localities. For this work is recommended an allotment of $1,700.

CENOZOIC.

It is proposed to confine the work on the Tertiary formations to the eastern United States, for the special purpose of clearing up the confusion relating to the faunas of the Miocene and Pliocene, and of assisting in the correlation of the Tertiary formations of Florida. This work will be in charge of Dr. William H. Dall, who will receive such temporary help as shall be necessary. For this work is recommended an allotment of $2,900.

PALEOBOTANY.

It is proposed that Prof. Lester F. Ward shall continue the preparation of his memoir on the flora of the Potomac formation and the Compendium of Paleobotany, and shall do such field work in the vicinity of Washington as may be necessary to obtain data for the flora of the Potomac formation.

Mr. David White will be attached to the geologic parties working in the coal-measures of Virginia and eastern Tennessee, to aid, through his knowledge of the fossil plants of the coal-bearing rocks, in correlating the various coal seams of the southern Appalachians. For the work of Prof. Ward is recommended an allotment of $2,300, and for that of Mr. White, $1,500.

VERTEBRATE PALEONTOLOGY.

It is proposed to continue this work by completing the preparation of monographs already ordered. This completed work will record the data useful to the geologist in correlating geologic formations in the coal-bearing deposits of the Rocky

Mountains and the great plains to the eastward. Immense collections have been gathered in years past, and Prof. O. C. Marsh will continue their study and prepare the monographs for publication. For this work is recommended an allotment of $2,000.

It is recommended that Mr. John W. Gentry, assistant paleontologist, be employed as a general assistant and clerk in the division, at a salary of $1,200.

MISCELLANEOUS.

CHEMICAL DIVISION.

It is proposed to continue the work of this division, as heretofore, under the direction of Mr. F. W. Clarke, assisted by W. F. Hillebrand. Mr. Clarke also has charge of the exhibit of the Geological Survey at the Columbian Exposition at Chicago.

The work of the Chemical Division consists in analyzing specimens of those rocks, coals, waters, etc., a knowledge of whose chemical composition is important for the purposes of the Survey. The appropriation for this work, for pay of all persons connected therewith and for purchase of chemical supplies, apparatus, etc., is $8,000.

DIVISION OF ILLUSTRATIONS.

This division has charge of field and office photography, the making of drawings and illustrations, and the editing of all graphic matter published by the Survey. It is proposed to continue it as heretofore under the direction of Mr. De Lancey W. Gill, who will be assisted by the corps of skilled experts who have been trained to this work. For the purchase of photographic supplies and all needful material, and for the pay of all persons employed, is allotted the entire appropriation of $13,000.

DIVISION OF MINING STATISTICS.

The sum appropriated for this work is $12,000. It is proposed to continue the collection and publication of statistics exhibiting the mineral resources of the United States, and to prepare and publish an annual volume, the work to be continued, as heretofore, under the direction of Dr. David T. Day.

DIVISION OF ENGRAVING AND PRINTING.

This division is charged with the work of engraving and printing the topographic and geologic atlas sheets produced by the Survey. From its creation in 1890 it has been in charge of Mr. S. J. Kübel. It is proposed to continue it under his direction and to do all the geologic map engraving and printing, all the topographic map printing, and part of the topographic map engraving in this division. Formerly all topographic map engraving was done by contract. Later, part was done in this division and part by contract. It is proposed to continue this last arrangement, which has been found to work well and advantageously for the Government. Out of the total appropriation of $55,000 for engraving and printing maps, it is proposed to set aside a sum sufficient to maintain the highest degree of efficiency and economy in the division, and to use the remainder in contract engraving.

DIVISION OF LIBRARY AND EXCHANGES.

The amount appropriated for the purchase of necessary books for the library and the payment for transmission of published documents through the Smithsonian exchange is $2,000. The amount necessary for the exchange through the Smithsonian Institution is estimated at $1,800, leaving $200 for the purchase of books not obtainable by exchange. It is proposed to continue Mr. C. C. Darwin in charge of this division.

EDITORIAL DIVISION.

It is proposed to continue Mr. W. A. Croffut in charge of this division, and that he shall be assisted by a small number of clerks detailed for the purpose, as need therefor arises.

RENT.

The total appropriation for rent for the Geological Survey is $14,200. The survey now occupies nearly all of the Hooe building, 1330 F street, and the top floor of the Adams building, 1333 and 1335 F street. It is proposed to vacate the Adams building shortly, and during the coming year to occupy instead a building in the rear of 1326 F street, formerly occupied by the Swiss laundry. This building is now being thoroughly overhauled and refitted, and promises to serve excellently as a home for the Engraving Division. The removal of the Engraving Division to the new home will permit an advantageous rearrangement of office room in the Hooe building.

DIVISION OF ACCOUNTS AND DISBURSEMENTS.

This division has been from the creation of the Survey in charge of Mr. John D. McChesney, under whose efficient management it is proposed to continue it. The disbursements of all appropriations for the Survey, the auditing of all its accounts, the accountability for its property, the preparation of all fiscal statements, the drawing of all contracts and bonds, and generally all the business of the Survey relating to money and property, is done in this division.

EXECUTIVE OFFICE

Under the immediate charge of the Director, through the chief clerk, Mr. H. C. Rizer, is a small body of clerks who attend to the miscellaneous business and the correspondence of the office. This office has charge of the miscellaneous files, the employment records, and all unclassified business of a general or miscellaneous character relating to the work of the Bureau. It is proposed in this office to continue the same general plan of work as in previous years.

ORGANIZATION AND PROGRESS OF THE YEAR'S WORK.

The following statement shows how this plan of operations, approved by the Secretary of the Interior, was practically realized:

TOPOGRAPHIC WORK.

During the year topographic work has been carried on by the Survey in twenty-one States and Territories, and an area of 35,650 square miles has been surveyed. Of this area, 23,505 square miles were surveyed upon a scale of 1:62500, with a contour interval of 20 or 25 feet; 10,950 square miles upon a scale of 1:125000, with a contour interval of 50 or 100 feet; and 1,180 square miles upon a scale of 1:250000, with a contour interval of 200 feet. The small area remaining is comprised in a detailed survey of a mining district of Colorado. The total area surveyed from the inception of the work in 1882 to date is 619,572 square miles, distributed over forty-nine States and Territories. This surveyed area is somewhat more than one-fifth the area of the country, excluding Alaska. The following table presents the area surveyed in each year since the beginning of the work:

Table showing annual progress of topographic mapping in square miles.

Year ending June 30—	Area	Year ending June 30—	Area
	Sq. miles.		*Sq. miles.*
1883	15,000	1889	64,472
1884	45,150	1890	67,650
1885	57,500	1891	65,575
1886	81,829	1892	53,000
1887	55,684	1893	26,000
1888	52,062	1894	35,650

The reduction in area in recent years is due to a combination of causes, among which are a reduction in the annual appropriation and an enlargement in the scale of work. In the earlier years most of the work was executed for a scale of 1:250000. As the work advanced, the requirements of geologists and of the general public increased, and consequently there has been a steady increase in the scale of the maps. As a result the scales of 1:125000 and 1:62500 have been introduced, and that of 1:250000 has been abandoned. Furthermore, there has been a steady increase in the proportion of work done upon the larger scales, the result of which is that two-thirds of the area surveyed during the past year has been done upon the scale 1:62500.

The following table illustrates the progress toward larger scales of work:

Year	Percent of total area on scales—		
	$\frac{1}{62500}$	$\frac{1}{125000}$	$\frac{1}{250000}$
1883	....	27	73
1884	1	46	53
1885	4	63	33
1886	5	72	23
1887	9	66	25
1888	7	67	26
1889	10	70	20
1890	17	83	....
1891	26	74	....
1892	15	85	....
1893	73	27	....
1894	66	31	3

The work of the past year completes 121 sheets, besides 4 detailed maps of mining districts upon a scale of 800 feet to an inch; 107 of these sheets are upon a scale of 1 : 62500, 13 upon a scale of 1 : 125000, and 1 upon a scale of 1 : 250000. The whole number of atlas sheets completed at the present time by survey and compilation is 906. Of these, 483 are on a scale of 1 : 62500, 361 upon a scale of 1 : 125000, and 62 upon a scale of 1 : 250000.

ORGANIZATION.

During the past year the organization of the topographic branch has remained substantially the same as last year, the work executed east of the one hundredth meridian being in charge of Mr. Henry Gannett, while that west of the one hundredth meridian has been in charge of Mr. A. H. Thompson. The clause in the sundry civil bill making appropriation for the topographic work stipulated that $70,000 should be expended east of the ninety-seventh meridian, $70,000 west of the one hundred and third meridian, and $60,000 between the ninety-seventh and one hundred and third. In order to carry out these provisions under the form of organization above specified, the appropriation of $60,000 for the region lying between the ninety-seventh and one hundred and third meridians was divided into two equal parts, half of which was expended east of the one hundredth meridian and half of it west of that line.

AREAS SURVEYED.

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 of Messrs. Henry Gannett and A. H. Thompson. The present condition of the topographic work is exhibited in the following tables:

Table showing by States and Territories the present condition of topographic surveys and the area surveyed in 1893-'94.[1]

State or Territory.	Total area.	Area surveyed to date	Area surveyed in 1893-'94.	Scale	Contour interval.
	Sq. miles.	*Sq. miles*	*Sq. miles.*		*Feet.*
Alabama	52,250	15,870	....	1:125000	50 and 100
Arizona	113,020	41,000	....	1:250000	200 and 250
Arkansas	53,850	15,000	....	1:125000	50
California	158,360	33,585	1,625	1: 62500 1:125000 1:250000	25,50,100,200 and 250
Colorado	103,925	35,080	265	1: 62500 1:125000 1:250000	25,50,100 and 250
Connecticut (completed)	4,990	4,990	....	1: 62500	20
Delaware	2,050	15	....	1: 62500	10
District of Columbia (completed)	70	70	....	1: 62500	20
Florida	58,680	1,900	....	1: 62500	10
Georgia	59,475	14,275	....	1:125000	50 and 100
Idaho	84,800	10,540	1,000	1:125000	25,50,and 100
Illinois	56,650	3,875	....	1: 62500 1:125000	5, 10, 20, and 50
Indiana	36,350	20	....	1: 62500	10
Indian Territory	31,400	250	....	1: 62500 1:125000	20 and 50
Iowa	56,025	4,450	....	1: 62500	20
Kansas	82,080	67,385	935	1: 62500 1:125000	20, 25, and 50
Kentucky	40,400	12,800	....	1:125000	100

[1] A few special surveys and maps are not included in this table.

Table showing by States and Territories the present condition of topographic surveys and the area surveyed in 1893-'94[1]—Continued.

State or Territory.	Total area.	Area surveyed to date.	Area surveyed in 1893-'94.	Scale.	Contour interval.
	Sq. miles.	*Sq. miles.*	*Sq. miles.*		*Feet.*
Louisiana	48,720	7,000	....	1: 62500	5
Maine	33,040	3,682	....	1: 62500	20
Maryland	12,210	6,930	....	1: 62500 1:125000	20,50, and 100
Massachusetts (completed)	8,315	8,315	....	1: 62500	20
Michigan	58,915	231	....	1: 62500	20
Minnesota	83,365	354	354	1: 62500	20
Missouri	69,415	26,000	....	1: 62500 1:125000	20 and 50
Montana	146,080	14,400	....	1:125000 1:250000	50, 100, and 200
Nebraska	77,510	10,590	8,140	1: 62500	20
Nevada	110,700	19,980	....	1:125000 1:250000	100, 200, and 250
New Hampshire	9,305	1,990	110	1: 62500	20
New Jersey (completed)	7,815	7,815	....	1: 62500	10 and 20
New Mexico	122,580	27,860	....	1:125000 1:250000	25, 50, 100, and 200
New York	49,170	9,136	5,250	1: 62500	20
North Carolina	52,250	11,111	411	1:125000	5, 50, and 100
North Dakota	70,795	2,960	2,060	1: 62500	20
Ohio	41,060	50	....	1:125000	100
Oklahoma	39,030	3,423	2,673	1: 62500	20
Oregon	96,030	12,180	1,180	1:250000	200
Pennsylvania	45,215	6,137	....	1: 62500	10 and 20
Rhode Island (completed)	1,250	1,250	....	1: 62500	20
South Carolina	30,570	4,350	....	1:125000	50 and 100
South Dakota	77,650	7,783	4,473	1: 62500 1:125000	20,50, and 100
Tennessee	42,050	18,309	1,214	1:125000	100
Texas	265,780	55,080	3,000	1:125000	25 and 50
Utah	84,970	6,000	....	1:250000	250
Vermont	9,565	1,500	150	1: 62500	20
Virginia	42,450	32,120	....	1: 62500 1:125000	5, 20, 50, and 100
Washington	69,180	210	210	1: 62500	25
West Virginia	24,780	22,500	....	1:125000	100
Wisconsin	56,040	6,540	....	1: 62500	20
Wyoming (including Yellowstone Park)	97,890	7,700	2,600	1:125000	25,50, and 100

[1] A few special surveys and maps are not included in this table.

In the following table the progress of topographic work is shown in greater detail, and various items of information are added with respect to each sheet:

List of topographic sheets surveyed in whole or in part.

Name and locality of atlas sheet.	Position of SE. corner of sheet. Lat.		Long.		Area covered.	Contour interval.	Scale.
	°	′	°	′		Feet.	
Abajo, Utah-Colo	37	00	109	00	1 degree	250	1:250000
Abbeville, S. C	34	00	82	00	¼ degree	50	1:125000
Aberdeen, S. Dak	45	15	98	15	1/16 degree	20	*a* 1: 62500
Abilene, Kans	38	30	97	00	¼ degree	50	1:125000
Abilene, Tex	32	00	99	30	....do	50	1:125000
Abingdon, Va.-Tenn.-N. C.	36	30	81	30	....do	100	1:125000
Abington, Mass	42	00	70	45	1/16 degree	20	1: 62500
Adrian, N. Dak	46	30	98	30	....do	20	*a* 1: 62500
Albany, Colo.-Kans	37	30	102	00	¼ degree	25	1:125000
Albany, N. Y	42	30	73	45	1/16 degree	20	1: 62500
Albany, Tex	32	30	99	00	¼ degree	50	1:125000
Albuquerque, N. Mex	35	00	106	30	....do	50	1:125000
Allentown, Pa	40	30	75	15	1/16 degree	20	1: 62500
Alma, Nebr	40	00	99	15	....do	20	*a* 1: 62500
Alpine, Tex	30	00	103	30	¼ degree	50	*a* 1:125000
Alton, Kans	39	15	98	45	1/16 degree	20	*a* 1: 62500
Alturas, Cal	41	00	120	00	1 degree	200	1:250000
Amana, Iowa	41	45	91	45	1/16 degree	20	1: 62500
Amsterdam, N. Y.	42	45	74	00	....do	20	*a* 1: 62500
Anamosa, Iowa	42	00	91	15	....do	20	1: 62500
Annapolis, Md	38	45	76	15	....do	20	1: 62500
Anniston, Ala	33	30	85	30	¼ degree	100	1:125000
Anson, Tex	32	30	99	30	....do	50	1:125000
Anthony, Kans	37	00	98	00	....do	20	1:125000
Anthracite, Colo	38	45	107	00	1/16 degree	100	1: 62500
Apishapa, Colo	37	30	104	00	¼ degree	25	1:125000
Appomattox, Va	37	00	78	30	....do	50	1:125000
Arapahoe, Nebr	40	15	99	45	1/16 degree	20	*a* 1: 62500
Archer, Nebr	41	00	98	00	....do	20	*a* 1: 62500
Arredondo, Fla	29	30	82	15	....do	10	1: 62500
Arroyo, Colo	38	30	103	00	¼ degree	25	1:125000
Asbury Park, N. J	40	00	74	00	1/16 degree	10	1: 62500
Asheville, N. C.-Tenn	35	30	82	30	¼ degree	100	1:125000
Ashland, Ala	33	00	85	30	....do	100	1:125000
Ashland, Nebr	41	00	96	15	1/16 degree	20	*a* 1: 62500
Ashland, Oreg	42	00	122	00	1 degree	200	1:250000

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet				Area covered	Contour interval	Scale
	Lat.		Long				
	°	′	°	′		*Feet.*	
Ashley, Utah-Colo	40	00	109	00	1 degree	250	1:250000
Aspen, Colo	39	00	106	45	1/16 degree	100	*a* 1: 62500
Atchison, Kans.-Mo	39	30	95	00	1/4 degree	50	1:125000
Atlanta, Ga	33	30	84	00	....do	50	1:125000
Atlantic City, N. J	39	15	74	15	1/16 degree	10	1: 62500
Augusta, Me	44	15	69	45	....do	20	1: 62500
Aurora, Nebr	40	45	98	00	....do	20	*a* 1: 62500
Ausable, N. Y	44	15	73	30	....do	20	*a* 1: 62500
Austin, Tex	30	00	97	30	1/4 degree	50	1:125000
Baird, Tex	32	00	99	00	....do	50	*a* 1:125000
Baldwin, Iowa	42	00	90	45	1/16 degree	20	1: 62500
Ballinger, Tex	31	30	99	30	1/4 degree	50	1:125000
Baltimore, Md	39	15	76	30	1/16 degree	20	1: 62500
Baraboo, Wis	43	15	89	30	....do	20	*a* 1: 62500
Barataria, La	29	30	90	00	....do	5	1: 62500
Barnegat, N. J	39	45	74	00	....do	10	1: 62500
Barnstable, Mass	41	32	70	15	....do	20	1: 62500
Barre, Mass	42	15	72	00	....do	20	1: 62500
Bastrop, Tex	30	00	97	00	1/4 degree	50	1:125000
Batesville, Ark	35	30	91	30	....do	50	1:125000
Bath, Me	43	45	69	45	1/16 degree	20	1: 62500
Bayou de Large, La	29	15	90	45	....do	None.	1: 62500
Bayside, N. J.-Del	39	15	75	15	....do	10	1: 62500
Bay View, Wis	42	45	87	45	....do	20	1: 62500
Bear Valley, Idaho	44	00	115	00	1/4 degree	100	1:125000
Beattyville, Ky	37	30	83	30	....do	100	1:125000
Beaver, Utah	38	00	112	00	1 degree	250	1:250000
Beaver City, Nebr	40	00	99	45	1/16 degree	20	*a* 1: 62500
Becket, Mass	42	15	73	00	....do	20	1: 62500
Belchertown, Mass	42	15	72	15	....do	20	1: 62500
Beloit, Kans	39	00	98	00	1/4 degree	20	1:125000
Bennington, Nebr.-Iowa	41	15	96	00	1/16 degree	20	*a* 1: 62500
Benton, Ark	34	30	92	30	1/4 degree	50	1:125000
Berlin, N. Y.-Mass.-Vt	42	30	73	15	1/16 degree	20	1: 62500
Bermuda Hundred, Va	37	15	77	15	....do	20	1: 62500
Bernal, N. Mex	35	00	105	00	1/4 degree	50	1:125000
Bertrand, Nebr	40	30	99	30	1/16 degree	20	*a* 1: 62500
Berwick, Me.-N. H	43	15	70	45	....do	20	1: 62500
Bessemer, Ala	33	00	86	30	1/4 degree	100	1:125000
Beverly, W. Va.-Va	38	30	79	30	....do	100	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered	Contour interval	Scale
	Lat.		Long				
	°	′	°	′		*Feet.*	
Biddeford, Me	43	15	70	15	$\frac{1}{16}$ degree	20	1: 62500
Bidwell Bar, Cal	39	30	121	00	$\frac{1}{4}$ degree	100	1:125000
BigSnowyMountain, Mont	46	00	109	00	1 degree	200	1:250000
Big Spring Lake, Wis	43	30	89	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Big Springs, Colo	38	30	104	00	$\frac{1}{4}$ degree	25	1:125000
Big Timber, Mont	45	30	109	30	do	50	1:125000
Big Trees, Cal	38	00	120	00	do	100	1:125000
Birmingham, Ala	33	30	86	30	do	100	1:125000
Bison, Kans	38	30	99	00	$\frac{1}{16}$ degree	20	*a* 1: 62500
Bisuka, Idaho	43	00	116	00	$\frac{1}{4}$ degree	25, 50, 100	1:125000
Blackstone, Mass.-R. I	42	00	71	30	$\frac{1}{16}$ degree	20	1: 62500
Bladen, Nebr	40	15	98	30	do	20	*a* 1: 62500
Blanco, Tex	30	00	98	00	$\frac{1}{4}$ degree	50	1:125000
Block Island, R. I	41	00	71	30	$\frac{1}{16}$ degree	20	1: 62500
Bloodsworth Island, Md	38	00	76	00	do	None.	*a* 1: 62500
Bloomsburg, Pa	41	00	76	15	do	20	1: 62500
Blue Hill, Nebr	40	15	98	15	do	20	*a* 1: 62500
Bodreau, La	29	45	89	15	do	None.	*a* 1: 62500
Boise, Idaho	43	30	116	00	$\frac{1}{4}$ degree	25, 100	1:125000
Bolivar, Mo	37	30	93	00	do	50	1:125000
Bonnet Carre, La	30	00	90	15	$\frac{1}{16}$ degree	5	1: 62500
Boonville, Mo	38	30	92	30	$\frac{1}{4}$ degree	50	1:125000
Boothbay, Me	43	45	69	30	$\frac{1}{16}$ degree	20	1: 62500
Bordentown, N. J.-Pa	40	00	74	30	do	10	1: 62500
Boston, Mass	42	15	71	00	do	20	1: 62500
Boston Bay, Mass	42	15	70	45	do	20	1: 62500
Brackettville, Tex	29	00	100	00	$\frac{1}{4}$ degree	25	*a* 1:125000
Brady, Tex	31	00	99	00	do	50	1:125000
Brandywine, Md	38	30	76	45	$\frac{1}{16}$ degree	20	1: 62500
Brattleboro, Vt.-N. H	42	45	72	30	do	20	1: 62500
Breckenridge, Tex	32	30	98	30	$\frac{1}{4}$ degree	50	1:125000
Briceville, Tenn	36	00	84	00	do	100	1:125000
Bridgeport, Conn	41	00	73	00	$\frac{1}{16}$ degree	20	1: 62500
Bridgeton, N. J	39	15	75	00	do	10	1: 62500
Bristol, Va.-Tenn	36	30	82	00	$\frac{1}{4}$ degree	100	1:125000
Brodhead, Wis	42	30	89	15	$\frac{1}{16}$ degree	20	1: 62500
Brookfield, Mass.-Conn	42	00	72	00	do	20	1: 62500
Brooklyn, N. Y	40	30	73	45	do	20	1: 62500
Brownwood, Tex	31	30	98	30	$\frac{1}{4}$ degree	50	1:125000
Buckeye, Nebr	40	45	98	45	$\frac{1}{16}$ degree	20	*a* 1: 62500
Buckhannon, W. Va	38	30	80	00	$\frac{1}{4}$ degree	100	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet.				Area covered.	Contour interval.	Scale.
	Lat.		Long.				
	°	′	°	′		Feet.	
Buckingham, Va	37	30	78	30	¼ degree	100	1:125000
Buffalo, N. Y	42	45	78	45	1/16 degree	20	1: 62500
Buggy Creek, Okla	35	15	98	00	....do	20	*a* 1: 62500
Bunker Hill, Kans	38	45	98	30	....do	20	*a* 1: 62500
Burden, Kans	37	00	96	30	¼ degree	50	1:125000
Burlingame, Kans	38	30	95	30	....do	50	1:125000
Burlington, Kans	38	00	95	30	....do	50	1:125000
Burlington, Pa.-N. J	40	00	74	45	1/16 degree	20	1: 62500
Burnet, Tex	30	30	98	00	¼ degree	50	1:125000
Burrillville, R. I	41	45	71	30	1/16 degree	20	1: 62500
Butler, Mo	38	00	94	00	¼ degree	50	1:125000
Buxton, Me	43	30	70	30	1/16 degree	20	1: 62500
Caldwell, Kans	37	00	97	30	¼ degree	20	1:125000
Calumet, Ill.-Ind	41	30	87	30	1/16 degree	10	1: 62500
Camas Prairie, Idaho	43	00	115	00	¼ degree	50, 100	1:125000
Cambridge, N. Y.-Vt	43	00	73	15	1/16 degree	20	*a* 1: 62500
Camp Mohave, Ariz.-Nev.-Cal	35	00	114	00	1 degree	250	1:250000
Canyon, Yellowstone National Park	44	30	110	00	¼ degree	100	1:125000
Canyon City, Colo	38	00	105	00	....do	25, 50, 100	1:125000
Canyon de Chelly, Ariz.-N. Mex	36	00	109	00	1 degree	200	1:250000
Cape May, N. J	38	45	74	45	1/16 degree	10	1: 62500
Cape Vincent, N. Y	44	00	76	15	....do	20	*a* 1: 62500
Carmel, N. Y.-Conn	41	15	73	30	....do	20	1: 62500
Carnesville, Ga.-S. C	34	00	83	00	¼ degree	50	1:125000
Carson, Nev	39	00	119	30	....do	100	1:125000
Cartersville, Ga	34	00	84	30	....do	100	1:125000
Carthage, Mo	37	00	94	00	....do	50	1:125000
Casco Bay, Me	43	30	70	00	1/16 degree	20	1: 62500
Cassville, N. J	40	00	74	15	....do	10	1: 62500
Castle Rock, Colo	39	00	104	30	¼ degree	50, 100	1:125000
Catawissa, Pa	40	45	76	15	1/16 degree	20	1: 62500
Cat Island, La.-Miss	30	00	89	00	....do	None.	1: 62500
Catlin, Colo	38	00	103	30	¼ degree	25	1:125000
Catskill, N. Y	42	00	73	45	1/16 degree	20	*a* 1: 62500
Cedar Bluffs, Nebr	41	15	96	30	....do	20	*a* 1: 62500
Cedar Rapids, Iowa	41	45	91	30	....do	20	1: 62500
Central City, Nebr	41	00	97	45	....do	20	*a* 1: 62500
Chaco, N. Mex	36	00	108	00	1 degree	200	1:250000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered.	Contour interval	Scale.
	Lat.		Long.				
	°	′	°	′		Feet.	
Chandeleur, La	29	45	89	00	1/16 degree	None.	1: 62500
Charleston, W. Va	38	00	81	30	¼ degree	100	1:125000
Charlestown, R. I	41	15	71	30	1/16 degree	20	1: 62500
Chatham, Mass	41	30	69	45	....do	20	1: 62500
Chattanooga, Tenn	35	00	85	00	¼ degree	100	1:125000
Chef Menteur, La	30	00	89	45	1/16 degree	None.	1: 62500
Cheney, Kans	37	30	97	30	¼ degree	20	1:125000
Chemere Caminada, La	29	00	90	00	1/16 degree	None.	1: 62500
Chesterfield, Mass	42	15	72	45	....do	20	1: 62500
Cheyenne Wells, Colo.-Kans	38	30	102	00	¼ degree	25	1:125000
Chicago, Ill	41	45	87	30	1/16 degree	5	1: 62500
Chico, Cal	39	30	121	30	¼ degree	100	1:125000
Chino, Ariz	35	00	112	00	1 degree	250	1:250000
Chispa. Tex	30	30	104	30	¼ degree	50	a 1:125000
Chittenango, N Y	44	00	75	45	1/16 degree	20	a 1: 62500
Christiansburg, Va.-W. Va.	37	00	80	00	¼ degree	100	1:125000
Citra, Fla	29	15	82	00	1/16 degree	10	a 1: 62500
Claflin, Kans	38	30	98	30	....do	20	a 1: 62500
Clanton, Ala	32	30	86	30	¼ degree	50	1:125000
Clay Center, Kans	39	00	97	00	....do	20	1:125000
Cleburne, Tex	32	00	97	00	....do	50	1:125000
Cleveland, Tenn	35	00	84	30	....do	100	1:125000
Clinton, Iowa-Ill	41	45	90	00	1/16 degree	20	1: 62500
Clinton, Mo	38	00	93	30	¼ degree	50	1.125000
Clove, N. Y.-Conn	41	30	73	30	1/16 degree	20	1. 62500
Codell, Kans	39	00	99	00	....do	20	a 1: 62500
Cohoes, N. Y	42	45	73	30	....do	20	1. 62500
Coldwater, Kans	37	00	99	00	¼ degree	20	1:125000
Coleman, Tex	31	30	99	00	....do	50	1:125000
Colfax, Cal	39	00	120	30	....do	100	1 125000
Colorado Springs, Colo	38	30	104	30	....do	25, 50, 100	1·125000
Columbia, S. Dak	45	30	98	15	1/16 degree	20	1: 62500
Columbus, Nebr	41	15	97	15	....do	20	a 1: 62500
Concordia, Kans	39	30	97	30	¼ degree	20	1·125000
Conde, S. Dak	45	00	98	00	1/16 degree	20	1: 62500
Corazon, N Mex	35	00	104	30	¼ degree	50	1:125000
Cornwall, Conn.-N. Y	41	45	73	15	1/16 degree	20	1: 62500
Cottonwood Falls, Kans	38	00	96	30	¼ degree	50	1:125000
Cowee, N. C-S. C	35	00	83	00	....do	100	1:125000
Coxsackie, N. Y	42	15	73	45	1/16 degree	20	1: 62500
Cozad, Nebr	40	45	99	45	....do	20	a 1: 62500

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered	Contour interval	Scale
	Lat		Long				
	°	′	°	′		Feet	
Cranberry, N. C.-Tenn	36	00	81	30	¼ degree	100	1 125000
Crandall Creek, Wyo	44	30	109	30	....do	100	a 1 125000
Crawford Notch, N H	44	00	71	15	1/16 degree	20	a 1. 62500
Creole, La	29	15	90	00	....do	None	1: 62500
Crested Butte, Colo	38	45	106	45	....do	100	1: 62500
Cullman, Ala	34	00	86	30	¼ degree	100	1:125000
Cumberland Gap, Ky - Va -Tenn	36	30	83	30	....do	100	1 125000
Cut Off, La	29	30	90	15	1/16 degree	5	1 62500
Dahlonega, Ga.-N C	34	30	83	30	¼ degree	100	1 125000
Dallas, Tex	32	30	96	30	....do	50	1 125000
Dalton, Ga -Tenn	34	30	84	30	....do	100	1.125000
Danbury, Conn	41	15	73	15	1/16 degree	20	1· 62500
Dannebrog, Nebr	41	00	98	30	....do	20	a 1 62500
Dardanelle, Ark	35	00	93	00	¼ degree	50	1:125000
Darlington, Okla	35	30	98	00	1/16 degree	20	a 1 62500
Davenport, Iowa-Ill	41	30	90	30	....do	20	1· 62500
Dayton, Wyo	44	45	107	00	¼ degree	100	a 1·125000
Deadwood, S Dak	44	00	103	30	....do	100	1 125000
Dedham, Mass	42	00	71	00	1/16 degree	20	1· 62500
Delavan, Wis	42	30	88	30	....do	20	1· 62500
Delaware Water Gap, Pa.-N. J	40	45	75	00	....do	20	1: 62500
Deming, N Mex	32	00	107	30	¼ degree	50	a 1:125000
Dennisville, N J	39	00	74	45	1/16 degree	10	1: 62500
Denver, East, Colo	39	30	104	30	¼ degree	50	1 125000
Denver, West; Colo	39	30	105	00	....do	50, 100	1·125000
Derby, Conn	41	15	73	00	1/16 degree	20	1: 62500
Desplaines, Ill	41	30	87	45	....do	10	1 62500
Dewitt, Iowa	41	45	90	30	....do	20	1: 62500
Diamond Creek, Ariz	35	00	113	00	1 degree	250	1.250000
Dickey, N. Dak	46	30	98	15	1/16 degree	20	a 1 62500
Dillon, Mont	45	00	112	00	1 degree	200	1 250000
Dime, La	29	30	89	30	1/16 degree	5	1: 62500
Disaster, Nev	41	00	118	00	1 degree	200	1.250000
Dodge, Kans	37	30	100	00	¼ degree	20	1.125000
Doland, S Dak	44	45	98	00	1/16 degree	20	a 1. 62500
Donaldsonville, La	30	00	90	45	....do	5	1: 62500
Dover, N. H -Me	43	00	70	45	....do	20	1· 62500
Downieville, Cal	39	30	120	30	¼ degree	100	1 125000
Downs, Okla	35	45	97	30	1/16 degree	20	a 1 62500
Doylestown, Pa.-N J	40	15	75	00	....do	20	1: 62500

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered	Contour interval.	Scale
	Lat		Long				
	°	′	°	′		Feet.	
Drum Point, Md	38	15	76	15	1/16 degree	20	1: 62500
Dublin, Va.-W. Va	37	00	80	30	1/4 degree	100	1:125000
Dulac, La	29	15	90	30	1/16 degree	5	1: 62500
Duluth, Minn	46	45	92	00	do	20	*a* 1: 62500
Dundaff, Pa	41	30	75	30	do	20	1: 62500
Dunlap, Ill	40	45	89	30	do	10	1: 62500
Dunnellon, Fla	29	00	82	15	do	10	1: 62500
Durant, Iowa	41	30	90	45	do	20	1: 62500
Durham, N. Y	42	15	74	00	do	20	1: 62500
Duxbury, Mass	42	00	70	30	do	20	1: 62500
Eagle, Wis	42	45	88	15	do	20	1: 62500
East Delta, La	29	00	89	00	do	None.	1: 62500
Eastland, Tex	32	00	98	30	1/4 degree	50	1:125000
Easton, Pa.-N. J	40	30	75	00	1/16 degree	20	1: 62500
East Tavaputs, Utah-Colo.	39	00	109	00	1 degree	250	1:250000
Echo Cliffs, Ariz	36	00	111	00	do	250	1:250000
Eckelson, N. Dak	46	45	98	15	1/16 degree	20	*a* 1: 62500
Eden, Tex	31	00	99	30	1/4 degree	50	1:125000
Edgeley, N. Dak	46	15	98	30	1/16 degree	20	*a* 1: 62500
Edmond, Okla	35	30	97	15	do	20	*a* 1: 62500
Elberton, Ga.-S. C	34	00	82	30	1/4 degree	50	1:125000
El Cajon, Cal	32	45	116	45	1/16 degree	25	1: 62500
Eldorado, Kans	37	30	96	30	1/4 degree	50	1:125000
Eldridge, N. Dak	46	45	98	45	1/16 degree	20	*a* 1: 62500
Elizabethtown, N. Y	44	00	73	30	do	20	1: 62500
Ellendale, N. Dak.-S. Dak.	45	45	98	30	do	20	1: 62500
Ellicott, Md	39	15	76	45	do	20	1: 62500
Ellijay, Ga.-N. C.-Tenn	34	30	84	00	1/4 degree	100	1:125000
Ellis, Kans	38	30	99	30	do	20	1:125000
Ellsworth, Kans	38	30	98	00	do	20	1:125000
Elm, S. Dak	45	30	98	30	1/16 degree	20	*a* 1: 62500
Elm Creek, Nebr	40	30	99	15	do	20	*a* 1: 62500
Elmira, N. Y	42	00	76	45	do	20	*a* 1: 62500
Elmoro, Colo	37	00	104	00	1/4 degree	25, 50, 100	1:125000
El Paso, Tex	31	30	106	00	do	25, 50	*a* 1:125000
Elreno, Okla	35	30	97	45	1/16 degree	20	*a* 1: 62500
Elwood, Nebr	40	30	99	45	do	20	*a* 1: 62500
Emporia, Kans	38	00	96	00	1/4 degree	50	1:125000
Englewood, Kans	37	00	99	45	1/16 degree	20	*a* 1: 62500
Escalante, Utah	37	00	111	00	1 degree	250	1:250000
Escondido, Cal	33	00	117	00	1/16 degree	25	1: 62500
Eskridge, Kans	38	30	96	00	1/4 degree	50	1:125000

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE corner of sheet				Area covered.	Contour interval.	Scale
	Lat		Long.				
	°	′	°	′		*Feet.*	
Estillville, Va.-Ky.-Tenn.	36	30	82	30	¼ degree..	100	1:125000
Eureka, Kans	37	30	96	00	....do	50	1:125000
Evansville, Wis	42	45	89	15	1/16 degree..	20	1: 62500
Fall River, Mass.-R. I	41	30	71	00	....do	20	1: 62500
Falmouth, Mass	41	30	70	30	....do	20	1: 62500
Farmville, Va	37	00	78	00	¼ degree...	50	1:125000
Fish Lake, Utah	38	00	111	00	1 degree...	250	1:250000
Fitchburg, Mass-N. H	42	30	71	45	1/16 degree..	20	1: 62500
Fonda, N. Y	42	45	74	15	....do	20	*a* 1: 62500
Fort Ann, N. Y.-Vt	43	15	73	15	....do	20	*a* 1. 62500
Fort Benton, Mont	47	00	110	00	1 degree...	200	1:250000
Fort Custer, Mont	45	30	107	30	¼ degree...	50	1:125000
Fort Defiance, Ariz.-N. Mex	35	00	109	00	1 degree...	200	1:250000
Fort Hancock, Tex	31	00	105	30	¼ degree...	50	1:125000
Fort Livingston, La	29	15	89	45	1/16 degree..	None.	1: 62500
Fort Logan, Mont	46	00	111	00	1 degree...	200	1:250000
Fort McKavett, Tex	30	30	100	00	¼ degree...	25	1:125000
Fort Payne, Ala.-Ga	34	00	85	30	....do	100	1:125000
Forts, La	29	15	89	15	1/16 degree..	None.	1: 62500
Fort Scott, Kans.-Mo	37	30	94	30	¼ degree ..	50	1:125000
Fort Smith, Ark -Ind. T	35	00	94	00	....do	50	1:125000
Fort Steele, Wyo	41	30	106	30	....do	25, 50	1:125000
Fort Worth, Tex	32	30	97	00	....do	50	1.125000
Framingham, Mass	42	15	71	15	1/16 degree..	20	1. 62500
Frankfort, S Dak	44	45	98	15	....do	20	*a* 1: 62500
Franklin, Mass -R I	42	00	71	15	....do	20	1: 62500
Franklin, Nebr	40	00	98	45	....do	20	*a* 1: 62500
Franklin, N. J	41	00	74	30	....do	20	1: 62500
Franklin, W. Va.-Va	38	30	79	00	¼ degree...	100	1:125000
Frederick, Md.-Va	39	00	77	00	....do	50	1:125000
Fredericksburg, Tex	30	00	98	30	....do	50	1:125000
Fredericksburg, Va.-Md	38	00	77	00	....do	50	1:125000
Fredonia, Kans	37	30	95	30	....do	50	1:125000
Freeport, Me	43	45	70	00	1/16 degree..	20	1: 62500
Fremont, Nebr	41	15	96	15	....do	20	*a* 1: 62500
Fullerton, Nebr	41	15	97	45	....do	20	*a* 1: 62500
Fullerton, N. Dak	46	00	98	15	....do	20	1: 62500
Fulton, Mo	38	30	91	30	¼ degree...	50	1:125000
Gadsden, Ala	34	00	86	00	....do	100	1:125000
Gainesville, Ga	34	00	83	30	....do	100	1:125000
Gallatin, Yellowstone National Park	44	30	110	30	....do	100	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE. corner of sheet				Area covered.	Contour interval	Scale
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Garden City, Kans	37	45	100	45	$\frac{1}{16}$ degree	20	*a* 1: 62500
Garden Valley, Idaho	44	00	115	30	$\frac{1}{4}$ degree	100	*a* 1:125000
Gardiner, Me	44	00	69	45	$\frac{1}{16}$ degree	20	1: 62500
Garnett, Kans	38	00	95	00	$\frac{1}{4}$ degree	50	1:125000
Gatesville, Tex	31	00	97	30	....do	50	1:125000
Gay Head, Mass	41	15	70	42	$\frac{1}{16}$ degree	20	1: 62500
Geneva, Wis	42	30	88	15	....do	20	1: 62500
Georgetown, Tex	30	30	97	30	$\frac{1}{4}$ degree	50	1:125000
Germantown, Pa.-N. J	40	00	75	00	$\frac{1}{16}$ degree	20	1: 62500
Gibson, La	29	30	90	45	....do	5	1: 62500
Gilead, Conn	41	30	72	15	....do	20	1: 62500
Glasgow, Mo	39	00	92	30	$\frac{1}{4}$ degree	50	1:125000
Glassboro, N. J	39	30	75	00	$\frac{1}{16}$ degree	10	1: 62500
Gloucester, Mass	42	30	70	30	....do	20	1: 62500
Goochland, Va	37	30	77	30	$\frac{1}{4}$ degree	50	1:125000
Goose Lake, Iowa-Ill	41	45	90	15	$\frac{1}{16}$ degree	20	1: 62500
Gordonsville, Va	38	00	78	00	$\frac{1}{4}$ degree	100	1:125000
Gorham, N. H.-Me	44	15	71	00	$\frac{1}{16}$ degree	20	1: 62500
Granada, Colo.-Kans	38	00	102	00	$\frac{1}{4}$ degree	25	1:125000
Granbury, Tex	32	00	97	30	....do	50	1:125000
Granby, Conn	41	45	72	45	$\frac{1}{16}$ degree	20	1: 62500
Grand Island, Nebr	40	45	98	15	....do	20	*a* 1: 62500
Granite Range, Nev	40	00	119	00	1 degree	200	1:250000
Grant Pass, Oreg	42	00	123	00	....do	200	*a* 1:250000
Granville, Mass.-Conn	42	00	72	45	$\frac{1}{16}$ degree	20	1: 62500
Gray, Me	43	45	70	15	....do	20	1: 62500
Great Bend, Kans	38	00	98	30	$\frac{1}{4}$ degree	20	1:125000
Great Egg Harbor, N. J	39	15	74	30	$\frac{1}{16}$ degree	10	1: 62500
Great Falls, Mont	47	00	111	00	1 degree	200	1:250000
Greeneville, Tenn.-N. C	36	00	82	30	$\frac{1}{4}$ degree	100	1:125000
Greenfield, Mass.-Vt	42	30	72	30	$\frac{1}{16}$ degree	20	1: 62500
Greenfield, Mo	37	00	93	30	$\frac{1}{4}$ degree	50	1:125000
Greenwood Lake, N.J.-N.Y	41	00	74	15	$\frac{1}{16}$ degree	20	1: 62500
Greylock, Mass.-Vt	42	30	73	00	....do	40	1: 62500
Groton, Mass.-N. H	42	30	71	30	....do	20	1: 62500
Groton, S. Dak	45	15	98	00	....do	20	*a* 1: 62500
Grundy, Va.-Ky	37	00	82	00	$\frac{1}{4}$ degree	100	1:125000
Guide Rock, Nebr	40	00	98	15	$\frac{1}{16}$ degree	20	*a* 1: 62500
Guilford, Conn	41	15	72	30	....do	20	1: 62500
Gunpowder, Md	39	15	76	15	....do	20	1: 62500
Guthrie, Okla	35	45	97	15	....do	20	*a* 1: 62500
Hackettstown, N. J	40	45	74	45	....do	20	1: 62500

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE. corner of sheet.				Area covered.	Contour interval.	Scale.
	Lat		Long.				
	°	'	°	'		*Feet.*	
Hahnville, La	29	45	90	15	$\frac{1}{16}$ degree	5	1: 62500
Hamilton, Tex	31	30	98	00	$\frac{1}{4}$ degree	50	1:125000
Hammonton, N. J	39	30	74	45	$\frac{1}{16}$ degree	10	1: 62500
Harlem, N. Y.-N. J	40	45	73	45	....do	20	1: 62500
Harney Peak, S. Dak	43	30	103	30	$\frac{1}{4}$ degree	100	*a* 1:125000
Harpers Ferry, Va.-W. Va.-Md	39	00	77	30	....do	100	1:125000
Harrisburg, Pa	40	15	76	45	$\frac{1}{16}$ degree	20	1: 62500
Harrisonburg, Va	38	00	78	30	$\frac{1}{4}$ degree	100	1:125000
Harrisonville, Mo	38	30	94	00	....do	50	1:125000
Hartford, Conn	41	45	72	30	$\frac{1}{16}$ degree	20	1: 62500
Hartland, Kans	37	45	101	15	....do	20	*a* 1: 62500
Harvey Lake, Pa	41	15	76	00	....do	20	1: 62500
Haverhill, Mass.-N. H	42	45	71	00	....do	20	1: 62500
Hawley, Mass.-Vt	42	30	72	45	....do	20	1: 62500
Hayrick, Tex	31	30	100	00	degree	50	1:125000
Hays, Kans	38	45	99	15	$\frac{1}{16}$ degree	20	*a* 1: 62500
Hazard, Ky	37	00	83	00	$\frac{1}{4}$ degree	100	1:125000
Hazleton, Pa	40	45	75	45	$\frac{1}{16}$ degree	20	1: 62500
Hecla, N. Dak.-S. Dak	45	45	98	00	....do	20	1: 62500
Helena, Mont	46	00	112	00	1 degree	200	1:250000
Hennepin, Ill	41	15	89	15	$\frac{1}{16}$ degree	10	1: 62500
Hennessey, Okla	36	00	97	45	....do	20	*a* 1: 62500
Henry Mountains, Utah	37	00	110	00	1 degree	250	1:250000
Hermann, Mo	38	30	91	00	$\frac{1}{4}$ degree	50	1:125000
Hermosa, S. Dak	43	30	103	00	....do	100	1:125000
Hiawatha, Kans	39	30	95	30	....do	50	1:125000
Hickory, N. C	35	30	81	00	....do	50	*a* 1:125000
Higbee, Colo	37	30	103	00	....do	25, 50	1:125000
High Bridge, N. J	40	30	74	45	$\frac{1}{16}$ degree	20	1: 62500
Hill, Kans	39	00	99	30	$\frac{1}{4}$ degree	20	1:125000
Hillsville, Va.-N. C	36	30	80	30	....do	100	1:125000
Hinton, W. Va	37	30	80	30	....do	100	1:125000
Hitchcock, S. Dak	44	30	98	15	$\frac{1}{16}$ degree	20	*a* 1: 62500
Hoisington, Kans	38	30	98	45	....do	20	*a* 1: 62500
Holbrook, Ariz	34	00	110	00	1 degree	200	1:250000
Holdrege, Nebr	40	15	99	15	$\frac{1}{16}$ degree	20	*a* 1: 62500
Honesdale, Pa	41	30	75	15	....do	20	1: 62500
Honey Lake, Cal	40	00	120	00	1 degree	200	1:250000
Hot Springs, Ark	34	30	93	00	$\frac{1}{4}$ degree	50	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE corner of sheet. Lat.		Long.		Area covered	Contour interval.	Scale.
	°	′	°	′		*Feet.*	
Houma, La	29	30	90	30	$\frac{1}{16}$ degree	5	1: 62500
Huerfano Park, Colo	37	30	105	00	$\frac{1}{4}$ degree	25, 50, 100	1:125000
Hummelstown, Pa	40	15	76	30	$\frac{1}{16}$ degree	20	1: 62500
Huntersville, W. Va	38	00	80	00	$\frac{1}{4}$ degree	100	1:125000
Huntington, W. Va.-Ohio	38	00	82	00	do	100	1:125000
Huntley, Mont	45	30	108	00	do	50	1:125000
Huntsville, Ala.-Tenn	34	30	86	30	do	100	1:125000
Hutchinson, Kans	38	00	97	30	do	20	1:125000
Idaho Basin, Idaho	43	30	115	30	do	100	1:125000
Independence, Kans	37	00	95	30	do	50	1:125000
Independence, Mo	39	00	94	00	do	50	1:125000
Iola, Kans	37	30	95	00	do	50	1:125000
Iowa City, Iowa	41	30	91	30	$\frac{1}{16}$ degree	20	1: 62500
Ishawooa, Wyo	44	00	109	30	$\frac{1}{4}$ degree	100	*a* 1:125000
Ithaca, N. Y	42	15	76	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Ivanhoe, Kans	37	30	100	45	do	20	*a* 1: 62500
Jackson, Cal	38	00	120	30	$\frac{1}{4}$ degree	100	1:125000
Jamestown, N. Dak	46	45	98	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Janesville, Wis	42	30	89	00	do	20	1: 62500
Jasper, Ala	33	30	87	00	$\frac{1}{4}$ degree	50	1:125000
Jefferson City, Mo	38	30	92	00	do	50	1:125000
Jemes, N. Mex	35	30	106	30	do	100	1:125000
Joliet, Ill	41	30	88	00	$\frac{1}{16}$ degree	10	1: 62500
Jonesville, Ky.-Va.-Tenn	36	30	83	00	$\frac{1}{4}$ degree	100	1:125000
Joplin, Kans.-Mo	37	00	94	30	do	50	1:125000
Junction City, Kans	39	00	96	30	do	50	1:125000
Kaaterskill, N. Y	42	00	74	00	$\frac{1}{16}$ degree	20	1: 62500
Kaibab, Ariz	36	00	112	00	1 degree	250	1:250000
Kanab, Utah	37	00	112	00	do	250	1:250000
Kanawha Falls, W. Va	38	00	81	00	$\frac{1}{4}$ degree	100	1:125000
Kansas City, Kans.-Mo	39	00	94	30	do	50	1:125000
Kearney, Nebr	40	30	99	00	$\frac{1}{16}$ degree	20	1: 62500
Kenesaw, Nebr	40	30	98	30	do	20	1: 62500
Kennebunk, Me	43	15	70	30	do	20	1: 62500
Kent, R. I	41	30	71	30	do	20	1: 62500
Kerrville, Tex	30	00	99	00	$\frac{1}{4}$ degree	50	1:125000
Kingfisher, Okla	35	45	97	45	$\frac{1}{16}$ degree	20	*a* 1: 62500
Kingman, Kans	37	30	98	00	$\frac{1}{4}$ degree	20	1:125000
Kingston, Tenn	35	30	84	30	do	100	1:125000
Kinsley, Kans	37	30	99	00	do	20	1:125000
Kit Carson, Colo	38	30	102	30	do	25	1:125000
Klamath, Oreg	42	00	121	00	1 degree	200	1:250000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE corner of sheet.				Area covered	Contour interval	Scale
	Lat.		Long.				
	°	′	°	′		Feet.	
Knoxville, Tenn.-N. C....	35	30	83	30	¼ degree...	100	1:125000
Koshkonong, Wis	42	45	88	45	1/16 degree..	20	1: 62500
Kulm, N Dak............	46	15	98	45	....do	20	*a* 1: 62500
Lac des Allemands, La....	29	45	90	30	....do	5	1: 62500
Lacey, Okla..............	36	00	98	00	....do	20	*a* 1: 62500
Lacon, Ill...............	41	00	89	15	....do	20	1: 62500
La Crosse, Kans..........	38	30	99	15	....do	20	*a* 1: 62500
La Fortuna, La...........	29	30	89	15	....do	None.	1: 62500
Lake, Yellowstone National Park-Wyo	44	00	110	00	¼ degree...	100	1:125000
Lake Byron, S. Dak	44	30	98	00	1/16 degree..	20	*a* 1: 62500
Lake Felicity, La.........	29	15	90	15	....do	5	1: 62500
Lake Hopatcong, N. J	40	45	74	30	....do	20	1: 62500
Lake Placid, N. Y	44	15	73	45	....do	20	*a* 1: 62500
Lamar, Colo..............	38	00	102	30	¼ degree...	25	1:125000
Lambertville, Pa.-N. J ...	40	15	74	45	1/16 degree..	20	1: 62500
Lamoure, N. Dak.........	46	15	98	15	....do	20	1: 62500
Lampasas, Tex	31	00	98	00	¼ degree...	50	1:125000
Lamy, N. Mex............	35	00	105	30	....do	50, 100	1:125000
Laramie, Wyo	41	00	105	30	....do	25	*a* 1:125000
Largo, N. Mex............	36	00	107	00	1 degree...	200	1:250000
Larned, Kans	38	00	99	00	¼ degree...	20	1:125000
La Sal, Utah-Colo........	38	00	109	00	1 degree...	250	1:250000
Lasalle, Ill...............	41	15	89	00	1/16 degree..	10	1: 62500
Las Animas, Colo.........	38	00	103	00	¼ degree...	25	1:125000
Las Cruces, N. Mex.......	32	00	106	30	....do	25, 50	1:125000
Lassen Peak, Cal.........	40	00	121	00	1 degree...	200	1:250000
Las Vegas, N. Mex........	35	30	105	00	¼ degree...	50	1:125000
La Union, N. Mex.-Texas.	31	30	106	30	....do	50	*a* 1:125000
Laurel, Md...............	39	00	76	45	1/16 degree..	20	1: 62500
Lawrence, Kans	38	30	95	00	¼ degree...	50	1:125000
Lawrence, Mass	42	30	71	00	1/16 degree..	20	1: 62500
Leadville, Colo...........	39	00	106	00	¼ degree...	25, 50, 100	1:125000
Lebanon, Pa..............	40	15	76	15	1/16 degree..	20	1: 62500
Leclaire, Iowa-Ill	41	30	90	15	....do	20	1: 62500
Leonardtown, Md	38	15	76	30	....do	20	1: 62500
Letitia, Kans.............	37	15	99	45	....do	20	*a* 1: 62500
Lewisburg, Va.-W. Va....	37	30	80	00	¼ degree...	100	1:125000
Lexington, Mo............	39	00	93	30	....do	50	1:125000
Lexington, Nebr..........	40	45	99	30	1/16 degree..	20	*a* 1: 62500
Lexington, Va............	37	30	79	00	¼ degree...	100	1:125000
Limon, Colo..............	39	00	103	30	....do	25	1:125000

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE corner of sheet				Area covered.	Contour interval.	Scale
	Lat.		Long.				
	°	'	°	'		Feet.	
Little Belt Mountain, Mont	46	00	110	00	1 degree	200	1:250000
Little Egg Harbor, N. J.	39	30	74	15	$\frac{1}{16}$ degree	10	1: 62500
Little Rock, Ark	34	30	92	00	$\frac{1}{4}$ degree	50	1:125000
Livingston, Mont.—Yellowstone National Park.	45	00	110	00	1 degree	200	1:250000
Llano, Texas	30	30	98	30	$\frac{1}{4}$ degree	50	1:125000
Lockport, Kans	37	30	100	30	$\frac{1}{16}$ degree	20	a 1: 62500
Lodi, Cal	38	00	121	00	$\frac{1}{4}$ degree	50, 100	1:125000
London, Ky	37	00	84	00	do	100	1:125000
Londonderry, Vt	43	00	72	45	$\frac{1}{16}$ degree	20	1: 62500
Long Beach, N. J	39	30	74	00	do	10	1: 62500
Long Valley, Nev	41	00	119	00	1 degree	200	1:250000
Loudon, Tenn	35	30	84	00	$\frac{1}{4}$ degree	100	1:125000
Louisiana, Mo.-Ill	39	00	91	00	do	50	1:125000
Lowell, Mass.-N. H	42	30	71	15	$\frac{1}{16}$ degree	20	1: 62500
Lucas, Kans	39	00	98	30	do	20	a 1: 62500
Luray, Va	38	30	78	00	$\frac{1}{4}$ degree	100	1:125000
Lykens, Pa	40	30	76	30	$\frac{1}{16}$ degree	20	1: 62500
Lynchburg, Va	37	00	79	00	$\frac{1}{4}$ degree	100	1:125000
Lyons, Kans	38	00	98	00	do	20	1:125000
McCormick, Ga.-S. C	33	30	82	00	do	50	1:125000
McMinnville, Tenn	35	30	85	30	do	100	1:125000
Madison, Wis	43	00	89	15	$\frac{1}{16}$ degree	20	1: 62500
Magazine Mountain, Ark	35	00	93	30	$\frac{1}{4}$ degree	50	1:125000
Mahanoy, Pa	40	45	76	00	$\frac{1}{16}$ degree	20	1: 62500
Manchester, Ky	37	00	83	30	$\frac{1}{4}$ degree	100	1:125000
Mankato, Kans	39	30	98	00	do	20	1:125000
Manti, Utah	39	00	111	00	1 degree	250	1:250000
Maquoketa, Iowa	42	00	90	30	$\frac{1}{16}$ degree	20	1: 62500
Marfa, Tex	30	00	104	00	$\frac{1}{4}$ degree	50	a 1:125000
Marietta, Ga	33	30	84	30	do	50	1:125000
Marion, Iowa	42	00	91	30	$\frac{1}{16}$ degree	20	1: 62500
Markleeville, Cal.-Nev	38	30	119	30	$\frac{1}{4}$ degree	100	1:125000
Marlboro, Mass	42	15	71	30	$\frac{1}{16}$ degree	20	1: 62500
Marseilles, Ill	41	15	88	30	do	10	1: 62500
Marshall, Ark	35	30	92	30	$\frac{1}{4}$ degree	50	1:125000
Marshall, Mo	39	00	93	00	do	50	1:125000
Marsh Pass, Ariz	36	00	110	00	1 degree	200	1:250000
Marthas Vineyard, Mass	41	15	70	27	$\frac{1}{16}$ degree	20	1: 62500
Marysville, Cal	39	00	121	30	$\frac{1}{4}$ degree	100	1:125000
Marysville, Kans	39	30	96	30	do	50	1:125000
Mason, Tex	30	30	99	00	do	50	1:125000

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet				Area covered	Contour interval.	Scale.
	Lat.		Long				
	°	′	°	′		*Feet.*	
Maurice Cove, N. J	39	00	75	00	1/16 degree	10	1: 62500
Maxwell, Nebr	41	00	100	30	....do	20	*a* 1: 62500
Maynardville, Tenn	36	00	83	30	1/4 degree	100	1:125000
Meade, Kans	37	00	100	00	....do	20	1:125000
Mechanicsville, Iowa	41	45	91	15	1/16 degree	20	1: 62500
Medicine Lodge, Kans	37	00	98	30	1/4 degree	20	1:125000
Mellette, S. Dak	45	00	98	15	1/16 degree	20	*a* 1: 62500
Meriden, Conn	41	30	72	45	....do	20	1: 62500
Meridian, Tex	31	30	97	30	1/4 degree	50	1:125000
Merricourt, N. Dak	46	00	98	45	1/16 degree	20	*a* 1: 62500
Mesa de Maya, Colo	37	00	103	30	1/4 degree	25, 50, 100	1:125000
Metamora, Ill	40	45	89	15	1/16 degree	10	1: 62500
Mexico, Mo	39	00	91	30	1/4 degree	50	1:125000
Middleboro, Mass	41	45	70	45	1/16 degree	20	1: 62500
Middletown, Conn	41	30	72	30	....do	20	1: 62500
Miller, Nebr	40	45	99	15	....do	20	*a* 1: 62500
Millersburg, Pa	40	30	76	45	....do	20	1: 62500
Milwaukee, Wis	43	00	87	45	....do	20	1: 62500
Minco, Okla.-Ind. T	35	15	97	45	....do	20	*a* 1: 62500
Minden, Nebr	40	30	98	45	....do	20	1: 62500
Minneapolis, Kans	39	00	97	30	1/4 degree	20	1:125000
Moberly, Mo	39	00	92	00	....do	50	1:125000
Modoc Lava Bed, Cal	41	00	121	00	1 degree	200	1:250000
Monango, N. Dak	46	00	98	30	1/16 degree	20	1: 62500
Monterey, Va.-W. Va	38	00	79	30	1/4 degree	100	1:125000
Monticello, Iowa	42	00	91	00	1/16 degree	20	1: 62500
Montross, Va.-Md	38	00	76	45	....do	20	1: 62500
Mooers, N. Y	44	45	73	30	....do	20	*a* 1: 62500
Moore, Okla	35	15	97	15	....do	20	*a* 1: 62500
Moosup, Conn.-R. I	41	30	71	45	....do	20	1: 62500
Morganton, N. C	35	30	81	30	1/4 degree	100	1:125000
Morrillton, Ark	35	00	92	30	....do	50	1:125000
Morris, Ill	41	15	88	15	1/16 degree	10	1: 62500
Morristown, N. J	40	45	74	15	....do	20	1: 62500
Morristown, Tenn	36	00	83	00	1/4 degree	100	1:125000
Mound City, Kans.-Mo	38	00	94	30	....do	50	1:125000
Mountain Home, Ark.-Mo	36	00	92	00	....do	50	1:125000
Mountain Home, Idaho	43	00	115	30	....do	50, 100	1:125000
Mountain View, Ark	35	30	92	00	....do	50	1:125000
Mount Airy, La	30	00	90	30	1/16 degree	5	1: 62500
Mount Carrizo, Colo	37	00	103	00	1/4 degree	25, 50, 100	1:125000
Mount Guyot, Tenn.-N. C	35	30	83	00	....do	100	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered	Contour interval.	Scale
	Lat		Long				
	°	′	°	′		Feet	
Mount Holly, N J	39	45	74	45	$\frac{1}{16}$ degree	10	1 62500
Mount Ida, Ark	34	30	93	30	$\frac{1}{4}$ degree	50	1 125000
Mount Marcy, N Y	44	00	73	45	$\frac{1}{16}$ degree	20	1 62500
Mount Mitchell, N C.-Tenn	35	30	82	00	$\frac{1}{4}$ degree	100	1 125000
Mount Taylor, N Mex	35	00	107	00	1 degree	200	1 250000
Mount Trumbull, Ariz	36	00	113	00	do	250	1 250000
Mount Vernon, Va -D C.-Md	38	30	77	00	$\frac{1}{4}$ degree	50	1:125000
Mount Washington, N H.	44	15	71	15	$\frac{1}{16}$ degree	20	1· 62500
Mullica, N J	39	30	74	30	do	10	1· 62500
Mulhall, Okla	36	00	97	15	do	20	*a* 1 62500
Murphy, Tenn —N C	35	00	84	00	$\frac{1}{4}$ degree	100	1 125000
Muskeget, Mass	41	15	70	12	$\frac{1}{16}$ degree	20	1 62500
Muskego, Wis	42	15	88	00	do	20	1. 62500
Nampa, Idaho-Ore	43	30	116	30	$\frac{1}{4}$ degree	25, 50, 100	1 125000
Nantahalah, N. C.—Tenn.	35	00	83	30	do	100	1 125000
Nantucket, Mass	41	13	69	57	$\frac{1}{16}$ degree	20	1· 62500
Naponee, Nebr	40	00	99	00	do	20	*a* 1: 62500
Narragansett Bay, R. I	41	30	71	15	do	20	1 62500
Natural Bridge, Va	37	30	79	30	$\frac{1}{4}$ degree	100	1·125000
Ned Lake, Mich	46	15	88	15	$\frac{1}{16}$ degree	20	*a* 1· 62500
Nepesta, Colo	38	00	104	00	$\frac{1}{4}$ degree	25	1·125000
Ness City, Kans	38	00	99	30	do	20	1·125000
Nevada, Mo	37	30	91	00	do	50	1 125000
New Bedford, Mass	41	30	70	45	$\frac{1}{16}$ degree.	20	1 62500
New Brunswick, N J	40	15	74	15	do	10	1 62500
Newburyport, Mass -N H.	42	45	70	45	do	20	1: 62500
Newfield, Me -N. H	43	30	70	45	do	20	1· 62500
New Haven, Conn	41	15	72	45	do	20	1 62500
New London, Conn -N. Y.	41	15	72	00	do	20	1· 62500
New Milford, Conn	41	30	73	15	do	20	1· 62500
New Orleans, La	29	45	90	00	do	5	1· 62500
Newport, R. I	41	15	71	15	do	20	1 62500
Newton, Kans	38	00	97	00	$\frac{1}{4}$ degree	50	1 125000
Niagara Falls, N Y	43	00	79	00	$\frac{1}{16}$ degree.	20	1 62500
Nicholas, W. Va	38	00	80	30	$\frac{1}{4}$ degree	100	1 125000
Norfolk, Va.-N C	36	30	76	00	do	5	1 125000
Norman, Okla -Ind T	35	00	97	15	$\frac{1}{16}$ degree	20	*a* 1 62500
Norridgewock, Me	44	30	69	45	do	20	1 62500
Northampton, Mass	42	15	72	30	do	20	1 62500
North Bend, Nebr	41	15	96	45	do	20	*a* 1 62500

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE. corner of sheet. Lat		Long		Area covered.	Contour interval	Scale
	°		°	′		*Feet.*	
North Conway, N. H.-Me.	44	00	71	00	1/16 degree..	20	1: 62500
North Platte, Nebr.......	41	00	100	45	....do	20	*a* 1: 62500
North Point, Md	39	00	76	15	....do	20	1: 62500
Northville, S. Dak	45	00	98	30	....do	20	*a* 1: 62500
Norton, Kans.............	39	30	99	30	1/4 degree...	20	1:125000
Norwalk, Conn.-N. Y	41	00	73	15	1/16 degree..	20	1: 62500
Norwich, Conn...........	41	30	72	00	....do	20	1: 62500
Nueces, Tex..............	29	30	100	00	1/4 degree...	50	1:125000
Oakes, N. Dak............	46	00	98	00	1/16 degree..	20	1: 62500
Ocala, Fla................	29	00	82	00	....do	10	*a* 1: 62500
Oceana, W. Va.-Va	37	30	81	30	1/4 degree ..	100	1:125000
Oceanside, Cal	33	00	117	15	1/16 degree..	25	1: 62500
Oconomowoc, Wis........	43	00	88	15	....do	20	1: 62500
Oelrich, S. Dak	43	00	103	00	1/4 degree...	50	*a* 1:125000
Oklahoma, Okla.-Ind. T..	35	15	97	30	1/16 degree..	20	*a* 1: 62500
Olathe, Kans.-Mo	38	30	94	30	1/4 degree...	50	1:125000
Omaha, Nebr.-Iowa	41	15	95	45	1/16 degree..	20	*a* 1: 62500
Omega, Okla	35	45	98	00	....do	20	*a* 1: 62500
Oneida, N. Y	43	00	75	30	....do	20	*a* 1: 62500
Oriskany, N. Y	43	00	75	15	....do	20	*a* 1: 62500
Osborne, Kans............	39	15	98	30	....do	20	*a* 1: 62500
Osceola, Nebr	41	00	97	30	....do	20	*a* 1: 62500
Oskaloosa, Kans.-Mo	39	00	95	00	1/4 degree...	50	1:125000
Ottawa, Ill...............	41	15	88	45	1/16 degree..	10	1: 62500
Owensville, Md...........	38	45	76	30	....do	20	1: 62500
Oxford, Iowa.............	41	30	91	45	....do	20	1: 62500
Oxford, Nebr.............	40	15	99	30	....do	20	*a* 1: 62500
Palmer, Mass.-Conn	42	00	72	15	....do	20	1: 62500
Palmyra, Va	37	30	78	00	1/4 degree ..	50	1:125000
Palo Pinto, Tex	32	30	98	00	....do	50	1:125000
Panasoffkee, Fla	28	45	82	00	1/16 degree .	10	*a* 1: 62500
Papillion, Nebr...........	41	00	96	00	....do	20	*a* 1: 62500
Paradise, Nev	41	00	117	00	1 degree ..	200	1:250000
Parkerville, Kans	38	30	96	30	1/4 degree ..	50	1:125000
Parsons, Kans............	37	00	95	00	....do	50	1:125000
Passage Island, Mich	48	00	88	15	1/16 degree .	20	*a* 1: 62500
Paterson, N. J.-N. Y	40	45	74	00	....do	20	1: 62500
Pemberton, N. J..........	39	45	74	30	....do	10	1: 62500
Perch Lake, Mich	46	15	88	30	....do	20	*a* 1: 62500
Petersburg, Va...........	37	00	77	15	....do	20	1: 62500
Philadelphia, Pa.-N. J ...	39	45	75	00	....do	10, 20	1: 62500
Phillipsburg, Kans	39	30	99	00	1/4 degree ..	20	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE corner of sheet				Area covered	Contour interval	Scale.
	Lat		Long				
	°	′	°	′		*Feet*	
Pickens, S. C.	34	30	82	30	¼ degree	100	1:125000
Piedmont, W. Va.-Md.	39	00	79	00	....do	100	1:125000
Pierceville, Kans	37	45	100	30	1/16 degree	20	*a* 1:62500
Pikes Peak, Colo	38	30	105	00	¼ degree	100	1:125000
Pikeville, Tenn	35	30	85	00	....do	100	1:125000
Pine Grove, Pa	40	30	76	15	1/16 degree	20	1:62500
Piney Point, Md.-Va	38	00	76	30	....do	20	1:62500
Pioche, Nev.-Utah	37	00	114	00	1 degree	250	1:250000
Pisgah, N. C.-S. C	35	00	82	30	¼ degree	100	1:125000
Pittsfield, Mass.-N. Y	42	15	73	15	1/16 degree	20	1:62500
Pittston, Pa	41	15	75	45	....do	20	1:62500
Placerville, Cal	38	30	120	30	¼ degree	100	1:125000
Plainfield, N. J	40	30	74	15	1/16 degree	20	1:62500
Plainville, Kans	39	00	99	15	....do	20	*a* 1:62500
Platte Canyon, Colo	39	00	105	00	¼ degree	25, 50, 100	1:125000
Plattsburg, N. Y.-Vt	44	30	73	15	1/16 degree	20	*a* 1:62500
Plattsmouth, Nebr.-Iowa	41	00	95	45	....do	20	*a* 1:62500
Pleasanton, Nebr	40	45	99	00	....do	20	*a* 1:62500
Plymouth, Mass	41	45	70	30	....do	20	1:62500
Pocahontas, Va.-W. Va	37	00	81	00	¼ degree	100	1:125000
Pointe a la Hache, La	29	30	89	45	1/16 degree	5	1:62500
Point Lookout, Md.-Va	38	00	76	15	....do	20	1:62500
Portage, Wis	43	30	89	15	....do	20	1:62500
Port Henry, N. Y.-Vt	44	00	73	15	....do	20	1:62500
Portland, Me	43	30	70	15	....do	20	1:62500
Port Washington, Wis	43	15	87	45	....do	20	1:62500
Poteau Mountain, Ark.-Ind. T	34	30	91	00	¼ degree	50	1:125000
Pottsville, Pa	40	30	76	00	1/16 degree	20	1:62500
Poughkeepsie, N. Y	41	30	73	45	....do	20	1:62500
Pratt, Kans	37	30	98	30	¼ degree	20	1:125000
Prescott, Ariz	34	00	112	00	1 degree	200	1:250000
Prestonsburg, Ky	37	30	82	30	¼ degree	100	1:125000
Price River, Utah	39	00	110	00	1 degree	250	1:250000
Prince Frederick, Md	38	30	76	30	1/16 degree	20	1:62500
Princeton, N. J	40	15	74	30	....do	10	1:62500
Providence, R. I.-Mass	41	45	71	15	....do	20	1:62500
Provincetown, Mass	42	00	70	00	....do	20	1:62500
Pueblo, Colo	38	00	104	30	¼ degree	25, 50	1:125000
Pulaski, N. Y	43	30	76	00	1/16 degree	20	*a* 1:62500
Putnam, Conn.-R. I	41	45	71	45	....do	20	1:62500
Putney, S. Dak	45	30	98	00	....do	20	*a* 1:62500
Pyramid Peak, Cal	38	30	120	00	¼ degree	100	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE. corner of sheet.				Area covered.	Contour interval.	Scale
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Quakertown, Pa	40	15	75	15	$\frac{1}{16}$ degree	20	1: 62500
Quarantine, La	29	15	89	30	do	5	1: 62500
Racine, Wis	42	30	87	45	do	20	1: 62500
Raleigh, W. Va	37	30	81	00	$\frac{1}{4}$ degree	100	1:125000
Ramapo, N. J.-N. Y	41	00	74	00	$\frac{1}{16}$ degree	20	1: 62500
Rapid, S. Dak	44	00	103	00	$\frac{1}{4}$ degree	50	1:125000
Reading, Pa	40	15	75	45	$\frac{1}{16}$ degree	20	1: 62500
Red Bluff, Cal	40	00	122	00	1 degree	200	1:250000
Red Cloud, Nebr	40	00	98	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Redfield, S. Dak	44	45	98	30	do	20	*a* 1: 62500
Redlands, Cal	34	00	117	00	do	50	*a* 1: 62500
Relay, Md	39	00	76	30	do	20	1: 62500
Reno, Nev	39	30	119	30	$\frac{1}{4}$ degree	100	1:125000
Rhinebeck, N. Y	41	45	73	45	$\frac{1}{16}$ degree	20	*a* 1: 62500
Richmond, Ky	37	30	84	00	$\frac{1}{4}$ degree	100	1:125000
Richmond, Va	37	30	77	15	$\frac{1}{16}$ degree	20	1: 62500
Rigolets, La.-Miss	30	00	89	30	do	None.	1: 62500
Ringgold, Ga.-Tenn	34	30	85	00	$\frac{1}{4}$ degree	100	1:125000
Riverside, Ill	41	45	87	45	$\frac{1}{16}$ degree	10	1: 62500
Roan Mountain, Tenn.-N.C.	36	00	82	00	$\frac{1}{4}$ degree	100	1:125000
Roanoke, Va	37	00	79	30	do	100	1:125000
Roby, Tex	32	30	100	00	do	25	1:125000
Rochester, N. Y	43	00	77	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Rock Springs, Tex	30	00	100	00	$\frac{1}{4}$ degree	25	1:125000
Rocky Bar, Idaho	43	30	115	00	do	100	1:125000
Rome, Ga.-Ala	34	00	85	00	do	100	1:125000
Romney, W. Va.-Va.-Md	39	00	78	30	do	100	1:125000
Rosebud, Mont	45	00	107	00	do	50	1:125000
Rouses Point, N. Y.-Vt	44	45	73	15	$\frac{1}{16}$ degree	20	*a* 1: 62500
Russell, Kans	38	45	98	45	do	20	*a* 1: 62500
Rutland, Vt	43	30	72	45	do	20	1: 62500
Sackets Harbor, N. Y	43	45	76	00	do	20	*a* 1: 62500
Sacramento, Cal	38	30	121	00	$\frac{1}{4}$ degree	100	1:125000
Saint Bernard, La	29	45	89	45	$\frac{1}{16}$ degree	5	1: 62500
Saint George, Utah	37	00	113	00	1 degree	250	1:250000
Saint George, W. Va	39	00	79	30	$\frac{1}{4}$ degree	100	1:125000
Saint Johns, Ariz.-N. Mex.	34	00	109	00	1 degree	200	1:250000
Saint Louis, East; Mo.-Ill.	38	30	90	00	$\frac{1}{16}$ degree	20	1: 62500
Saint Louis, West; Mo.-Ill	38	30	90	15	do	20	1: 62500
Saint Paul, Nebr	41	00	98	15	do	20	*a* 1: 62500
Saint Thomas, Nev.-Ariz	36	00	114	00	1 degree	250	1:250000
Saint Xavier, Mont	45	00	107	30	$\frac{1}{4}$ degree	50, 100	1:125000

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet				Area covered.	Contour interval.	Scale
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Sakonnet, R. I	41	15	71	00	1/16 degree	20	1: 06250
Salem, Mass	42	30	70	45	....do	20	1: 62500
Salem, N. J	39	30	75	15	....do	10	1: 62500
Salina, Kans	38	30	97	30	¼ degree	20	1:125000
Salt Basin, Tex	31	30	105	00	....do	50	1:125000
Salt Lake, Utah	40	00	111	00	1 degree	250	1:250000
Saluda, N. C.-S. C	35	00	82	00	¼ degree	100	1:125000
Salyersville, Ky	37	30	83	00	....do	100	1:125000
San Angelo, Tex	31	00	100	00	....do	50	1:125000
San Bernardino, Cal	34	00	117	15	1/16 degree	50	1: 62500
Sanborn, Colo	38	30	103	30	¼ degree	25	1:125000
Sandisfield, Mass.-Conn	42	00	73	00	1/16 degree	20	1: 62500
Sandy Hook, N. J	40	15	74	00	....do	10	1: 62500
San Francisco M't'n, Ariz	35	00	111	00	1 degree	250	1:250000
San Francisco, Cal	37	45	122	15	1/16 degree	25	*a* 1: 62500
San Mateo, Cal	37	30	122	15	....do	25	*a* 1: 62500
San Pedro, N. Mex	35	00	106	00	¼ degree	50, 100	1:125000
San Rafael, Utah	38	00	110	00	1 degree	250	1:250000
San Saba, Tex	31	00	98	30	¼ degree	50	1:125000
Santa Clara, N. Mex	35	30	106	00	....do	100	1:125000
Santa Fe, N. Mex	35	30	105	30	....do	100	1:125000
Savanna, Iowa-Ill	42	00	90	00	1/16 degree	20	1: 62500
Savo, N. Dak.-S. Dak	45	45	98	15	....do	20	1: 62500
Saybrook, Conn	41	15	72	15	....do	20	1: 62500
Schenectady, N. Y	42	45	73	45	....do	20	1: 62500
Schuyler, Nebr	41	15	97	00	....do	20	*a* 1: 62500
Scottsboro, Ala.-Tenn	34	30	86	00	¼ degree	100	1:125000
Scranton, Pa	41	15	75	30	1/16 degree	20	1: 62500
Sea Isle, N. J	39	00	74	30	....do	10	1: 62500
Seattle, Wash	47	30	122	15	....do	25	*a* 1: 62500
Sedalia, Mo	38	30	93	00	¼ degree	50	1:125000
Sedan, Kans	37	00	96	00	....do	50	1:125000
Seneca, Kans	39	30	96	00	....do	50	1:125000
Sevier Desert, Utah	39	00	112	00	1 degree	250	1:250000
Sewanee, Tenn	35	00	85	30	¼ degree	100	1.125000
Shamokin, Pa	40	45	76	30	1/16 degree	20	1: 62500
Shailow, N. Dak	46	30	98	45	....do	20	*a* 1: 62500
Sharps Island, Md	38	30	76	15	....do	None.	1: 62500
Shasta, Cal	41	00	122	00	1 degree	200	1:250000
Sheffield, Mass.-Conn.-N. Y	42	00	73	15	1/16 degree	20	1: 62500
Shell Beach, La	29	45	89	30	....do	None.	1: 62500
Shellsburg, Iowa	42	00	91	45	....do	20	1: 62500

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet.				Area covered.	Contour interval.	Scale.
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Sheridan, Okla	36	00	97	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Sherwood, Tex	31	00	100	30	$\frac{1}{4}$ degree	25	*a* 1:125000
Shickshinny, Pa	41	00	76	00	$\frac{1}{16}$ degree	20	1: 62500
Shopiere, Wis	42	30	88	45	....do	20	1: 62500
Shoshone, Yellowstone National Park–Wyo	44	00	110	30	$\frac{1}{4}$ degree	100	1:125000
Sierra Blanca, Tex	31	00	105	00	....do	50	*a* 1:125000
Sierraville, Cal	39	30	120	00	....do	100	1:125000
Silver City, Idaho	43	00	116	30	....do	100	1:125000
Silver Creek, Nebr	41	15	97	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Silver Lake, Wis	42	30	88	00	....do	20	1: 62500
Sitka, Kans	37	00	99	30	....do	20	1: 62500
Small Point, Me	43	30	69	45	....do	20	1: 62500
Smartsville, Cal	39	00	121	00	$\frac{1}{4}$ degree	100	1:125000
Smith Center, Kans	39	30	98	30	....do	20	1:125000
Snake Creek, S. Dak	45	15	98	30	$\frac{1}{16}$ degree	20	*a* 1: 62500
Sodville, Kans	37	15	99	30	....do	20	*a* 1: 62500
Somerville, N. J	40	30	74	30	....do	20	1: 62500
Sonora, Cal	37	30	120	00	$\frac{1}{4}$ degree	50, 100	1:125000
Spanish Fort, La	30	00	90	00	$\frac{1}{16}$ degree	None.	1: 62500
Spearville, Kans	37	30	99	30	$\frac{1}{4}$ degree	20	1:125000
Spottsylvania, Va	38	00	77	30	....do	50	1:125000
Springfield, Colo	37	00	102	30	....do	25, 50	1:125000
Springfield, Mass.–Conn	42	00	72	30	$\frac{1}{16}$ degree	20	1: 62500
Springfield, Mo	37	00	93	00	$\frac{1}{4}$ degree	50	1:125000
Springville, Ala	33	30	86	00	....do	100	1:125000
Squaw Creek, Idaho	44	00	116	00	....do	100	1:125000
Stamford, Conn.–N. Y	41	00	73	30	$\frac{1}{16}$ degree	20	1: 62500
Stamford, Nebr	40	00	99	30	....do	20	*a* 1: 62500
Staten Island, N. Y.–N. J	40	30	74	00	....do	20	1: 62500
Statesville, N. C	35	30	80	30	$\frac{1}{4}$ degree	50	1:125000
Staunton, Va.–W. Va	38	00	79	00	....do	100	1:125000
Stephenville, Tex	32	00	98	00	....do	50	1:125000
Stevenson, Ala.–Ga.–Tenn	34	30	85	30	....do	100	1:125000
Stillwater, Mont	45	30	109	00	$\frac{1}{4}$ degree	50	1:125000
Stillwater, Okla	36	00	97	00	$\frac{1}{16}$ degree	20	*a* 1: 62500
Stockton, Kans	39	15	99	15	....do	20	*a* 1: 62500
Stockton, Mo	37	30	93	30	$\frac{1}{4}$ degree	50	1:125000
Stonington, Conn.–R. I.–N. Y	41	15	71	45	$\frac{1}{16}$ degree	20	1: 62500
Stony Island, N. Y	43	45	76	15	....do	20	*a* 1: 62500
Stoughton, Wis	42	45	89	00	....do	20	1: 62500

a Not printed.

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet.				Area covered.	Contour interval	Scale.
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Sunbury, Pa	40	45	76	45	1/16 degree	20	1: 62500
Sun Prairie, Wis	43	00	89	00	....do	20	1: 62500
Sutton, W. Va	38	30	80	30	1/4 degree	100	1:125000
Suwanee, Ga	34	00	84	00	....do	100	1:125000
Sweetwater, Tex	32	00	100	00	....do	25	1:125000
Syracuse, N. Y	43	00	76	00	1/16 degree	20	*a* 1: 62500
Talladega, Ala	33	00	86	00	1/4 degree	100	1:125000
Tallapoosa, Ga.-Ala	33	30	85	00	....do	100	1:125000
Tarrytown, N. Y.-N. J	41	00	73	45	1/16 degree	20	1: 62500
Taunton, Mass	41	45	71	00	....do	20	1: 62500
Taylor, Tex	30	30	97	00	1/4 degree	50	1:125000
Tazewell, Va.-W. Va	37	00	81	30	....do	100	1:125000
Temple, Tex	31	00	97	00	....do	50	1:125000
Thibodeaux, La	29	45	90	45	1/16 degree	5	1: 62500
Three Forks, Mont	45	00	111	00	1 degree	200	1:250000
Timbalier, La	29	00	90	15	1/16 degree	None.	1: 62500
Timpas, Colo	37	30	103	30	1/4 degree	25, 50	1:125000
Tipton, Iowa	41	45	91	00	1/16 degree	20	1: 62500
Tolland, Conn	41	45	72	15	....do	20	1: 62500
Tonawanda, N. Y	44	00	78	45	....do	20	1: 62500
Tooele Valley, Utah	40	00	112	00	1 degree	250	1:250000
Topeka, Kans	39	00	95	30	1/4 degree	50	1:125000
Toulme, La.-Miss	30	00	89	15	1/16 degree	None	1: 62500
Trinidad, Colo	37	00	104	30	1/4 degree	25, 50, 100	1:125000
Troy, N. Y	42	30	73	30	1/16 degree	20	1: 62500
Truckee, Cal	39	00	120	00	1/4 degree	100	1:125000
Tsala Apopka, Fla	28	45	82	15	1/16 degree	10	*a* 1: 62500
Tuckahoe, N. J	39	15	74	45	....do	10	1: 62500
Tusayan, Ariz	35	00	110	00	1 degree	200	1:250000
Tuscumbia, Mo	38	00	92	00	1/4 degree	50	1:125000
Two Butte, Colo	37	30	102	30	....do	25, 50	1:125000
Uinta, Utah	40	00	110	00	1 degree	250	1:250000
Upland, Nebr	40	15	98	45	1/16 degree	20	*a* 1: 62500
Valley Junction, N. Dak	46	15	98	00	....do	20	*a* 1: 62500
Vassalboro, Me	44	15	69	30	....do	20	1: 62500
Verde, Ariz	34	00	111	00	1 degree	200	1:250000
Versailles, Mo	38	00	92	30	1/4 degree	50	1:125000
Victoria, Kans	38	45	99	00	1/16 degree	20	*a* 1: 62500
Vilas, Colo.-Kans	37	00	102	00	1/4 degree	25	1:125000
Virginia Beach, Va.-N. C	36	30	75	30	....do	5	1:125000
Wabuska, Nev	39	00	119	00	....do	100	1:125000
Waco, Tex	31	30	97	00	....do	50	1:125000

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet.	Position of SE. corner of sheet.				Area covered.	Contour interval	Scale.
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Wadsworth, Nev	39	30	119	00	$\frac{1}{4}$ degree	100	1:125000
Waldo, Kans	39	00	98	45	$\frac{1}{16}$ degree	20	*a* 1: 62500
Walhalla, Ga.-S. C.-N. C.	34	30	83	00	$\frac{1}{4}$ degree	100	1:125000
Wallingford, Vt	43	15	72	45	$\frac{1}{16}$ degree	20	1: 62500
Wallpack, N. J.-Pa	41	00	74	45	....do	20	1: 62500
Walsenburg, Colo	37	30	104	30	$\frac{1}{4}$ degree	25, 50, 100	1:125000
Wamego, Kans	39	00	96	00	....do	50	1:125000
Warfield, W. Va.-Ky.-Va.	37	30	82	00	....do	100	1:125000
Warrensburg, Mo	38	30	93	30	....do	50	1:125000
Warrenton, Va	38	30	77	30	....do	50	1:125000
Warsaw, Mo	38	00	93	00	....do	50	1:125000
Wartburg, Tenn	36	00	84	30	....do	100	*a* 1:125000
Warwick, Mass.-N.H.-Vt.	42	30	72	15	$\frac{1}{16}$ degree	20	1: 62500
Washington, Kans	39	30	97	00	$\frac{1}{4}$ degree	20	1:125000
Washington, East; Md.-D. C	38	45	76	45	$\frac{1}{16}$ degree	20	1: 62500
Washington, West; Md.-D. C.-Va	38	45	77	00	....do	20	1: 62500
Waterbury, Conn	41	30	73	00	....do	20	1: 62500
Waterloo, Wis	43	00	88	45	....do	20	1: 62500
Watertown, N. Y	43	45	75	45	....do	20	*a* 1: 62500
Watertown, Wis	43	00	88	30	....do	20	1: 62500
Waterville, Me	44	30	69	30	....do	20	1: 62500
Watrous, N. Mex	35	30	104	30	$\frac{1}{4}$ degree	50	1:125000
Waukesha, Wis	43	00	88	00	$\frac{1}{16}$ degree	20	1: 62500
Weatherford, Tex	32	30	97	30	$\frac{1}{4}$ degree	50	1:125000
Webster, Mass.-Conn.-R.I.	42	00	71	45	$\frac{1}{16}$ degree	20	1: 62500
Wellfleet, Mass	41	45	69	55	....do	20	1: 62500
Wellington, Cal.-Nev	38	30	119	00	$\frac{1}{4}$ degree	100	1:125000
Wellington, Kans	37	00	97	00	....do	50	1:125000
West Delta, La	29	00	89	15	$\frac{1}{16}$ degree	None.	1: 62500
West Liberty, Iowa	41	30	91	15	....do	20	1: 62500
West Los Angeles, Cal	34	00	118	15	....do	50	*a* 1: 62500
West Point, N. Y	41	15	73	45	....do	20	1: 62500
Wheatland, Iowa	41	45	90	45	....do	20	1: 62500
Whitehall, N. Y.-Vt	43	30	73	15	....do	20	*a* 1: 62500
Whitesburg, Ky.-Va	37	00	82	30	$\frac{1}{4}$ degree	100	1:125000
Whitewater, Wis	42	45	88	30	$\frac{1}{16}$ degree	20	1: 62500
Whitings, N. J	39	45	74	15	....do	10	1: 62500
Wichita, Kans	37	30	97	00	$\frac{1}{4}$ degree	50	1:125000
Wicomico, Md.-Va	38	15	76	45	$\frac{1}{16}$ degree	20	1: 62500

a Not printed

List of topographic sheets surveyed in whole or in part—Continued.

Name and locality of atlas sheet	Position of SE. corner of sheet.				Area covered.	Contour interval	Scale
	Lat.		Long.				
	°	′	°	′		*Feet.*	
Wilcox, Nebr	40	15	99	00	1/16 degree	20	*a* 1: 62500
Wilkesbarre, Pa	41	00	75	45	....do	20	1: 62500
Wilkesboro, N. C	36	00	81	00	¼ degree	100	1:125000
Williamsburg, Ky.-Tenn	36	30	84	00	....do	100	1:125000
Williston, Fla	29	15	82	15	1/16 degree	10	*a* 1: 62500
Willsboro, N. Y.-Vt	44	15	73	15	....do	20	*a* 1: 62500
Wilmington, Ill	41	15	88	00	....do	10	1: 62500
Wilmington, Vt	42	45	72	45	....do	20	1: 62500
Wilson, N. Y	43	15	78	45	....do	20	1: 62500
Wilton Junction, Iowa	41	30	91	00	....do	20	1: 62500
Winchendon, Mass.-N. H	42	30	72	00	....do	20	1: 62500
Winchester, Va.-W. Va	39	00	78	00	¼ degree	100	1:125000
Wingate, N. Mex	35	00	108	00	1 degree	200	1:250000
Winsted, Conn	41	45	73	00	1/16 degree	20	1: 62500
Wiscasset, Me	44	00	69	30	....do	20	1: 62500
Wood River, Nebr	40	45	98	30	....do	20	*a* 1: 62500
Woodstock, Conn	41	45	72	00	....do	20	1: 62500
Woodstock, Va.-W. Va	38	30	78	30	¼ degree	100	1:125000
Woodston, Kans	39	15	99	00	1/16 degree	20	*a* 1: 62500
Worcester, Mass	42	15	71	45	....do	20	1: 62500
Wytheville, Va.-N. C	36	30	81	00	¼ degree	100	1:125000
Yadkinville, N C	36	00	80	30	....do	100	1:125000
Yarmouth, Mass	41	30	70	00	1/16 degree	20	1: 62500
Yellville, Ark	36	00	92	30	¼ degree	50	1:125000
York, Me -N H	43	00	70	30	1/16 degree	20	1: 62500
Yosemite, Cal	37	30	119	30	¼ degree	100	*a* 1:125000
Yukon, Okla	35	30	97	30	1/16 degree	20	*a* 1: 62500

a Not printed

That the preceding table may be conveniently used to show the progress of work in each State the following list is appended, showing the surveyed atlas sheets within each State.

List of topographic sheets, wholly or partly surveyed, arranged by States.

ALABAMA

Anniston
Ashland
Bessemer.
Birmingham
Clanton.
Cullman.
Fort Payne
Gadsden.
Huntsville
Jasper
Rome.
Tallapoosa.
Talladega.
Scottsboro.
Springville.
Stevenson.

ARIZONA

Camp Mohave.
Canyon de Chelly.
Chino.
Diamond Creek.
Echo Cliffs.
Fort Defiance.
Holbrook.
Kaibab
Marsh Pass
Mount Trumbull.
Prescott.
Saint Johns.
Saint Thomas.
Verde
Tusayan
San Francisco Mountain

ARKANSAS.

Batesville.
Benton.
Dardanelle
Fort Smith
Hot Springs.
Little Rock
Magazine Mountain.
Marshall.
Morrillton.
Mountain Home.
Mountain View
Mount Ida.
Poteau Mountain
Yellville

CALIFORNIA.

Alturas.
Bidwell Bar
Big Trees
Camp Mohave
Chico.
Colfax
Downieville
El Cajon
Escondido.
Honey Lake
Jackson.
Lassen Peak.
Lodi
Markleeville
Marysville.
Modoc Lava Bed
Oceanside.
Placerville
Pyramid Peak.
Red Bluff
Redlands.
Sacramento
San Bernardino.
San Francisco
San Mateo
Shasta.
Sierraville
Smartsville
Sonora.
Truckee.
Wellington
West Los Angeles
Yosemite.

COLORADO

Abajo.
Albany.
Anthracite.
Apishapa
Arroyo.
Ashley
Aspen.
Big Springs.
Canyon City.
Castle Rock.
Catlin.
Cheyenne Wells.
Colorado Springs.
Crested Butte
Denver, East.
Denver, West.
East Tavaputs.
Elmoro.
Granada
Higbee.
Huerfano Park.
Kit Carson
Lamar
La Sal.
Las Animas
Leadville.
Limon
Mesa de Maya
Mount Carrizo.
Nepesta
Pikes Peak
Platte Canyon.
Pueblo.
Sanborn
Springfield.
Timpas
Trinidad
Two Butte.
Vilas.
Walsenburg.

Connecticut.

Bridgeport.
Brookfield.
Carmel.
Clove.
Cornwall.
Danbury.
Derby.
Gilead.
Granby.
Granville.
Guilford.
Hartford.
Meriden.
Middletown.
Moosup.
New Haven.
New London.
New Milford
Norwalk.
Norwich.
Palmer.
Putnam
Sandisfield.
Saybrook.
Sheffield.
Springfield
Stamford
Stonington
Tolland
Waterbury.
Webster.
Winsted.
Woodstock.

Delaware

Bayside.

District of Columbia

Mount Vernon.
Washington, East
Washington, West

Florida.

Arredondo
Citra.
Dunnellon.
Ocala.
Panasoffkee
Tsala Apopka
Williston

Georgia

Atlanta.
Carnesville
Cartersville
Dahlonega.
Dalton.
Elberton
Ellijay.
Fort Payne
Gainesville.
McCormick.
Marietta
Ringgold
Rome.
Stevenson.
Suwanee.
Tallapoosa
Walhalla

Idaho.

Bear Valley
Bisuka
Boise.
Camas Prairie
Garden Valley.
Idaho Basin.
Mountain Home.
Nampa
Rocky Bar
Silver City
Squaw Creek

Illinois.

Calumet.
Chicago.
Clinton
Davenport.
Desplaines.
Dunlap
Goose Lake.
Hennepin.
Joliet
Lacon
Lasalle.
Leclaire.
Louisiana
Marseilles.
Metamora.
Morris
Ottawa
Riverside
Saint Louis, East
Saint Louis. West.
Savanna.
Wilmington

Indiana

Calumet

Indian Territory.

Fort Smith.
Minco
Norman
Oklahoma
Poteau Mountain

IOWA.

Amana.
Anamosa.
Baldwin.
Bennington.
Cedar Rapids.
Clinton.
Davenport.
Dewitt.
Durant.
Goose Lake.
Iowa City.
Leclaire.
Maquoketa.
Marion.
Mechanicsville.
Monticello.
Omaha.
Oxford.
Plattsmouth.
Savanna.
Shellsburg.
Tipton.
West Liberty.
Wheatland.
Wilton Junction.

KANSAS.

Abilene.
Albany.
Alton.
Anthony.
Atchison.
Beloit.
Bison.
Bunker Hill.
Burden.
Burlingame.
Burlington.
Caldwell.
Cheney.
Cheyenne Wells.
Claflin.
Clay Center.
Codell.
Coldwater.
Concordia.
Cottonwood Falls.
Dodge.
Eldorado.
Ellis.
Ellsworth.
Emporia.
Englewood.
Eskridge.
Eureka.
Fort Scott.
Fredonia.
Garden City.
Garnett.
Granada.
Great Bend.
Hartland.
Hays.
Hiawatha.
Hill.
Hoisington.
Hutchinson.
Independence.
Iola.
Ivanhoe.
Joplin.
Junction City.
Kansas City.
Kingman.
Kinsley.
La Crosse.
Larned.
Lawrence.
Letitia.
Lockport.
Lucas.
Lyons.
Mankato.
Marysville.
Meade.
Medicine Lodge.
Minneapolis.
Mound City.
Ness City.
Newton.
Norton.
Olathe.
Osborne.
Oskaloosa.
Parkerville.
Parsons.
Phillipsburg.
Pierceville.
Plainville.
Pratt.
Russell.
Salina.
Sedan.
Seneca.
Sitka.
Smith Center
Sodville.
Spearville.
Stockton.
Topeka.
Victoria.
Vilas.
Waldo.
Wamego.
Washington.
Wellington.
Wichita.
Woodston.

KENTUCKY

Beattyville.
Cumberland Gap.
Estillville.
Grundy.
Hazard.
Jonesville.
London.
Manchester.
Prestonburg.
Richmond.
Salyersville.
Warfield.
Whitesburg.
Williamsburg.

Louisiana.

Barataria.
Bayou de Large.
Bodreau.
Bonnet Carre.
Cat Island.
Chandeleur.
Chef Menteur.
Cheniere Caminada
Creole.
Cut Off.
Dime.
Donaldsonville.
Dulac.
East Delta.
Fort Livingston.
Forts.
Gibson.
Hahnville.
Houma.
Lac des Allemands.
La Fortuna.
Lake Felicity.
Mount Airy.
New Orleans.
Pointe a la Hache.
Quarantine.
Rigolets.
Saint Bernard.
Shell Beach.
Spanish Fort.
Thibodeaux.
Timbalier.
Toulme.
West Delta.

Maine.

Augusta.
Bath.
Berwick.
Biddeford.
Boothbay.
Buxton.
Casco Bay.
Dover.
Freeport.
Gardiner.
Gorham.
Gray.
Kennebunk.
Newfield.
Norridgewock.
North Conway.
Portland.
Small Point.
Vassalboro.
Waterville.
Wiscasset.
York.

Maryland.

Annapolis.
Baltimore.
Bloodsworth Island.
Brandywine.
Drum Point.
Ellicott.
Frederick.
Fredericksburg.
Gunpowder.
Harpers Ferry.
Laurel.
Leonardtown.
Montross.
Mount Vernon.
North Point.
Owensville.
Piedmont.
Piney Point.
Point Lookout.
Prince Frederick.
Relay.
Romney.
Sharps Island.
Washington, East.
Washington, West.
Wicomico.

Massachusetts.

Abington.
Barnstable.
Barre.
Becket.
Belchertown.
Berlin.
Blackstone.
Boston.
Boston Bay.
Brookfield.
Chatham.
Chesterfield.
Dedham.
Duxbury.
Fall River.
Falmouth.
Fitchburg.
Framingham.
Franklin.
Gay Head.
Gloucester.
Granville.
Greenfield.
Greylock.
Groton.
Haverhill.
Hawley.
Lawrence.
Lowell.
Marlboro.
Marthas Vineyard.
Middleboro.
Muskeget.
Nantucket.
New Bedford.
Newburyport.
Northampton.
Palmer.
Pittsfield.
Plymouth.
Providence.
Provincetown.
Salem.
Sandisfield.
Sheffield.
Springfield.
Taunton.
Warwick.
Webster.
Wellfleet.
Winchendon.
Worcester.
Yarmouth.

MICHIGAN.

Ned Lake.	Passage Island.	Perch Lake.

MINNESOTA.

Duluth.

MISSISSIPPI.

Cat Island.	Rigolets.	Toulme.

MISSOURI.

Atchison.	Independence.	Olathe.
Bolivar.	Jefferson City.	Oskaloosa.
Boonville.	Joplin.	Saint Louis, East.
Butler.	Kansas City.	Saint Louis, West.
Carthage.	Lexington.	Sedalia.
Clinton.	Louisiana.	Springfield.
Fort Scott.	Marshall.	Stockton.
Fulton.	Mexico.	Tuscumbia.
Glasgow.	Moberly.	Versailles.
Greenfield.	Mound City.	Warrensburg.
Harrisonville.	Mountain Home.	Warsaw.
Hermann.	Nevada.	Yellville.

MONTANA.

Big Snowy Mountain.	Fort Logan.	Livingston.
Big Timber.	Great Falls.	Rosebud.
Dillon.	Helena.	Saint Xavier.
Fort Benton.	Huntley.	Stillwater.
Fort Custer.	Little Belt Mountain.	Three Forks.

NEBRASKA.

Alma.	Elm Creek.	North Platte.
Arapahoe.	Elwood.	Omaha.
Archer.	Franklin.	Osceola.
Ashland.	Fremont.	Oxford.
Aurora.	Fullerton.	Papillion.
Beaver City.	Grand Island.	Plattsmouth.
Bennington.	Guide Rock.	Pleasanton.
Bertrand.	Holdrege.	Red Cloud.
Bladen.	Kearney.	Saint Paul.
Blue Hill.	Kenesaw.	Schuyler.
Buckeye.	Lexington.	Silver Creek.
Cedar Bluffs.	Maxwell.	Stamford.
Central City.	Miller.	Upland.
Columbus.	Minden.	Wilcox.
Cozad.	Naponee.	Wood River.
Dannebrog.	North Bend.	

NEVADA.

Camp Mohave.	Markleeville.	Wabuska.
Carson.	Paradise.	Wadsworth.
Disaster.	Pioche.	Wellington.
Granite Range.	Reno.	
Long Valley.	Saint Thomas.	

NEW HAMPSHIRE.

Berwick.
Brattleboro.
Crawford Notch.
Dover.
Fitchburg.
Gorham.
Groton.
Haverhill.
Lowell.
Mount Washington.
Newburyport.
Newfield.
North Conway.
Warwick.
Winchendon.
York.

NEW JERSEY.

Asbury Park.
Atlantic City.
Barnegat.
Bayside.
Bordentown.
Bridgeton.
Burlington.
Cape May.
Cassville.
Delaware Water Gap.
Dennisville.
Doylestown.
Easton.
Franklin.
Germantown.
Glassboro.
Great Egg Harbor.
Greenwood Lake.
Hackettstown.
Hammondton.
Harlem.
High Bridge.
Lake Hopatcong.
Lambertville.
Little Egg Harbor.
Long Beach.
Maurice Cove.
Morristown.
Mount Holly.
Mullica.
New Brunswick.
Paterson.
Pemberton.
Philadelphia.
Plainfield.
Princeton.
Ramapo.
Salem.
Sandy Hook.
Sea Isle.
Somerville.
Staten Island.
Tarrytown.
Tuckahoe.
Wallpack.
Whitings.

NEW MEXICO.

Albuquerque.
Bernal.
Canyon de Chelly.
Chaco.
Corazon.
Deming.
Fort Defiance.
Jemes.
Lamy.
Largo.
Las Cruces.
Las Vegas.
La Union.
Mount Taylor.
Saint Johns.
San Pedro.
Santa Fe.
Santa Clara
Watrous.
Wingate.

NEW YORK.

Albany.
Amsterdam.
Ausable.
Berlin.
Brooklyn.
Buffalo.
Cambridge.
Cape Vincent.
Carmel.
Catskill.
Chittenango.
Clove.
Cohoes.
Cornwall.
Coxsackie.
Durham.
Elizabethtown.
Elmira.
Fonda.
Fort Ann.
Greenwood Lake.
Harlem.
Ithaca.
Kaaterskill.
Lake Placid.
Mooers.
Mount Marcy.
New London.
Niagara Falls.
Norwalk.
Oneida.
Oriskany.
Paterson.
Pittsfield.
Plattsburg.
Port Henry.
Poughkeepsie.
Pulaski.
Ramapo.
Rhinebeck.
Rochester.
Rouses Point.
Sackets Harbor.
Schenectady.
Sheffield.
Stamford.
Staten Island.
Stonington.
Stony Island.
Syracuse.
Tarrytown.
Tonawanda.
Troy.
Watertown.
West Point.
Whitehall.
Willsboro.
Wilson.

NORTH CAROLINA.

Abingdon.
Asheville.
Cowee.
Cranberry.
Dahlonega.
Ellijay.
Greeneville.
Hickory.
Hillsville.
Knoxville.
Morganton.
Mount Guyot.
Mount Mitchell.
Murphy.
Nantahalah.
Norfolk.
Pisgah.
Roan Mountain.
Saluda.
Statesville.
Virginia Beach.
Walhalla.
Wilkesboro.
Wytheville.
Yadkinville.

NORTH DAKOTA.

Adrian.
Dickey.
Eckelson.
Edgeley.
Eldridge.
Ellendale.
Fullerton.
Hecla.
Jamestown.
Kulm.
Lamoure.
Merricourt.
Monango.
Oakes.
Savo.
Sharlow.
Valley Junction.

OHIO.

Huntington.

OKLAHOMA.

Buggy Creek.
Darlington.
Downs.
Edmond.
Elreno.
Guthrie.
Hennessey.
Kingfisher.
Lacey.
Minco.
Moore.
Mulhall.
Norman.
Oklahoma
Omega.
Sheridan.
Stillwater.
Yukon.

OREGON.

Ashland.
Grant Pass.
Klamath.
Nampa.

PENNSYLVANIA.

Allentown.
Bloomsburg.
Bordentown.
Burlington.
Catawissa.
Delaware Water Gap.
Doylestown.
Dundaff.
Easton.
Germantown.
Harrisburg.
Harvey Lake.
Hazleton.
Honesdale.
Hummelstown.
Lambertville.
Lebanon.
Lykens.
Mahanoy.
Millersburg.
Philadelphia.
Pine Grove.
Pittston.
Pottsville.
Quakertown.
Reading.
Scranton.
Shamokin.
Shickshinny.
Sunbury.
Wallpack.
Wilkesbarre.

RHODE ISLAND.

Blackstone.
Block Island.
Burrillville.
Charlestown.
Fall River.
Franklin.
Kent.
Moosup.
Narragansett Bay.
Newport.
Providence.
Putnam.
Sakonnet.
Stonington.
Webster.

SOUTH CAROLINA.

Abbeville.
Carnesville.
Cowee.
Elberton.
McCormick.
Pickens.
Pisgah.
Saluda.
Walhalla.

SOUTH DAKOTA.

Aberdeen.
Columbia.
Conde.
Deadwood.
Doland.
Ellendale.
Elm.
Frankfort.
Groton.
Harney Peak.
Hecla.
Hermosa.
Hitchcock.
Lake Byron.
Mellette.
Northville.
Oelrich.
Putney.
Rapid.
Redfield.
Savo.
Snake Creek.

TENNESSEE.

Abingdon.
Asheville.
Briceville.
Bristol.
Chattanooga
Cleveland.
Cranberry.
Cumberland Gap.
Dalton.
Ellijay.
Estillville.
Greeneville.
Huntsville.
Jonesville.
Kingston.
Knoxville.
London.
McMinnville.
Maynardville.
Morristown.
Mount Guyot.
Mount Mitchell.
Murphy.
Nantahalah.
Pikeville.
Ringgold.
Roan Mountain.
Scottsboro.
Sewanee.
Stevenson.
Wartburg.
Williamsburg.

TEXAS.

Abilene.
Albany.
Alpine.
Anson.
Austin.
Baird.
Ballinger.
Bastrop.
Blanco.
Brackettville.
Brady.
Breckenridge.
Brownwood.
Burnet.
Chispa.
Cleburne.
Coleman.
Dallas.
Eastland.
Eden.
El Paso.
Fort Hancock.
Fort McKavett.
Fort Worth.
Fredericksburg.
Gatesville.
Georgetown.
Granbury.
Hamilton.
Hayrick.
Kerrville.
Lampasas.
La Union.
Llano.
Marfa.
Mason.
Meridian.
Nueces.
Palo Pinto
Roby.
Rock Springs.
Salt Basin.
San Angelo.
San Saba.
Sherwood.
Sierra Blanca.
Stephenville.
Sweetwater.
Taylor.
Temple.
Waco.
Weatherford.

UTAH.

Abajo.
Ashley.
Beaver.
East Tavaputs.
Escalante.
Fish Lake.
Henry Mountains.
Kanab.
La Sal.
Manti.
Pioche.
Price River.
Saint George.
Salt Lake.
San Rafael.
Sevier Desert.
Tooele Valley.
Uinta.

Vermont.

Berlin.
Brattleboro.
Cambridge.
Fort Ann.
Hawley.
Greenfield.
Greylock.
Londonderry.
Plattsburg.
Port Henry.
Rouses Point.
Rutland.
Wallingford
Warwick.
Whitehall.
Willsboro.
Wilmington.

Virginia

Abingdon.
Appomattox.
Bermuda Hundred.
Beverly.
Bristol.
Buckingham.
Christiansburg.
Cumberland Gap.
Dublin.
Estillville.
Farmville.
Franklin.
Frederick.
Fredericksburg.
Goochland.
Gordonsville.
Grundy.
Harpers Ferry
Harrisonburg.
Hillsville.
Jonesville.
Lewisburg.
Lexington.
Luray.
Lynchburg
Monterey.
Montross.
Mount Vernon.
Natural Bridge.
Norfolk.
Oceana.
Palmyra.
Petersburg.
Piney Point.
Pocahontas.
Point Lookout.
Richmond.
Roanoke.
Romney.
Spottsylvania.
Staunton.
Tazewell.
Virginia Beach
Warfield.
Warrenton.
Washington, West.
Whitesburg.
Wicomico.
Winchester.
Woodstock.
Wytheville.

Washington.

Seattle.

West Virginia.

Beverly.
Buckhannon.
Charleston.
Christiansburg.
Dublin.
Franklin.
Harpers Ferry.
Hinton.
Huntersville.
Huntington.
Kanawha Falls.
Lewisburg.
Monterey.
Nicholas.
Oceana.
Piedmont.
Pocahontas.
Raleigh.
Romney.
Saint George.
Staunton.
Sutton.
Tazewell.
Warfield.
Winchester.
Woodstock

Wisconsin.

Baraboo.
Bay View.
Big Spring Lake.
Brodhead.
Delavan.
Eagle.
Evansville.
Geneva.
Janesville.
Koshkonong.
Madison.
Milwaukee.
Muskego.
Oconomowoc.
Portage.
Port Washington.
Racine.
Shopiere.
Silver Lake
Stoughton
Sun Prairie
Waterloo.
Watertown
Waukesha.
Whitewater.

WYOMING.

Crandall Creek.
Dayton.
Fort Steele.
Ishawooa.
Lake.
Laramie.
Shoshone.

YELLOWSTONE NATIONAL PARK.

Canyon.
Gallatin.
Lake.
Livingston.
Shoshone.

Table showing distribution by States of atlas sheets surveyed to June 30, 1894.

State or Territory.	Wholly in State.	Partly in State.	State or Territory.	Wholly in State.	Partly in State.
Alabama	10	6	Nebraska	44	3
Arizona	11	5	Nevada	8	5
Arkansas	10	4	New Hampshire	2	14
California	30	3	New Jersey	30	16
Colorado	32	8	New Mexico	16	4
Connecticut	18	15	New York	32	26
Delaware	....	1	North Carolina	6	19
District of Columbia	....	3	North Dakota	14	3
Florida	7	....	Ohio	....	1
Georgia	5	12	Oklahoma	15	3
Idaho	10	1	Oregon	3	1
Illinois	13	9	Pennsylvania	23	9
Indiana	....	1	Rhode Island	7	8
Indian Territory	....	5	South Carolina	2	7
Iowa	17	8	South Dakota	19	3
Kansas	80	11	Tennessee	11	21
Kentucky	7	7	Texas	48	4
Louisiana	31	3	Utah	13	5
Maine	16	6	Vermont	5	12
Maryland	14	12	Virginia	17	34
Massachusetts	30	23	Washington	1	....
Michigan	3	....	West Virginia	10	16
Minnesota	1	....	Wisconsin	25	....
Mississippi	....	3	Wyoming	5	2
Missouri	24	12	Yellowstone National Park	2	3
Montana	14	1			

In addition to the single atlas sheets of the preceding list the Geological Survey has from time to time printed larger sheets formed by the combination of two or more of these.

List of combined sheets.

Locality.	Scale.	Contour interval
		Feet.
New York and vicinity	1: 62500	20
Albany and vicinity	1: 62500	20
Niagara Falls and vicinity	1: 62500	20
East and West Washington, District of Columbia, Maryland and Virginia	1: 62500	20
East and West St. Louis, Missouri and Illinois	1: 62500	20
Sandy Hook and Long Branch, New Jersey	1: 62500	10
Norfolk and Virginia Beach, Virginia	1:125000	5
East and West Denver, Colorado	1:125000	50, 100
Yellowstone National Park, Wyoming	1:125000	100

There have also been surveyed a number of special maps not constituting part of the atlas of the United States, viz:

Special maps.

Locality.	Scale	Contour interval
Aspen, Colorado	1: 9600	25
Banner Hill, California	1 .14400	20
Grass Valley, California	1:14400	20
Genesee, California	1:31680	50
Taylorsville, California	1:31680	50
Indian Valley, California	1:65500	100
Nevada City, California	1:14400	20
Hunter Park, Colorado	*a* 1: 9600	25
Tourtelotte Park, Colorado	*a* 1: 9600	25
Richmond Hill, Colorado	*a* 1: 9600	25
Lenado, Colorado	*a* 1: 9600	25

a Not printed.

Miscellaneous topographic maps.

	Scale.	Sheets
Contour map of the United States	1: 2500000	9
Contour map of the United States	1: 7000000	1
Hypsometric map of the United States	1: 7000000	1
Index map of the United States	1: 2500000	9
Base map of the United States	1: 7000000	1
Base map of the United States	1:14000000	1
Contour map of the State of Massachusetts	1: 250000	4
Contour map of the State of Connecticut	1: 125000	2
Contour map of the drainage basin of the Arkansas River in Colorado	1: 380160	2

GEOLOGIC WORK.

ORGANIZATION.

The appropriation for geologic work for the fiscal year ending June 30, 1893, was much smaller than the previous appropriations, and it was necessary to reduce the geologic corps. Field work was almost entirely stopped, and the energies of the force were devoted to the office work of preparing accumulated material for permanent record or publication. For the present fiscal year the appropriation was greater by about 30 per cent. This increase of funds and the advanced condition of office work made it possible to prosecute a large amount of field work, and also to resume several investigations which had been stopped.

The resumption of field work was accompanied by a reorganization of the geologic force. From the time of the organization of the Survey by its first Director, Mr. Clarence King, the geologic corps had been grouped in divisions, each under the immediate direction of a chief of division. Divisions were abolished from time to time, as the investigations assigned them were completed, and new divisions were created. Some divisions comprised a number of assistants, others only one, and in a few instances the work of a single individual was given divisional rank; but the general plan of organization gave to each of the more experienced geologists the supervision of the work of a group of assistants and made him correspondingly responsible for the results. As the younger men added experience from year to year, the necessity for subordinating their work to that of others gradually ceased, and as opportunity afforded they were placed in charge of independent investigations; but the magnitude and continuity of the larger bodies of work interfered to a certain extent with the plan, and the divisions came to consist in large part of geologists well equipped for independent work. It happened that the legislative action reducing the corps in the last fiscal year had the effect of retiring from the work several chiefs of important divisions, and it was decided that the partial reorganization thus necessitated should be made general. All divisions within the geologic corps were accordingly abolished, and when field work was resumed each geologist and assistant geologist was made a chief of party, performing his geologic work either alone or with the assistance of a relatively inexperienced man, classed as a field assistant or geologic aid.

The number of geologic field parties was about twenty, and the coordination of their work involved a considerable amount of supervision and inspection. To aid me in this branch of administrative work Mr. C. D. Walcott, previously chief paleontologist of the Survey, was called upon to take general charge also of the geologic work. The paleontologic force was reorganized in the same manner as the geologic, and the geologists, assistant geologists, paleontologists, and assistant paleontologists were instructed to report directly to Mr. Walcott, who received from the Secretary of the Interior an appointment as Geologist in charge of Geology and Paleontology. The entire geologic and paleontologic force was thus reorganized as a single division, coordinate, from an administrative point of view, with the topographic and accessory divisions of the Survey.

FIELD WORK.

Nearly all the field work of the year had for its immediate and direct purpose the preparation of the geologic atlas of the United States. The greater part of the time was directly devoted to the mapping of formations on the atlas sheets. To a certain extent revision was found necessary in order to settle questions which had been raised in the progress of office work during the preceding year; to a certain extent also reconnoissance was necessary to aid in the establishment of categories for the classification of formations in various districts; but final areal work on new ground and the correlative structural determinations were carried forward more rapidly than during any preceding year.

This areal work determines the extent and position of the various rock bodies and delineates them on the maps. It also determines the direction of their probable extent beneath the surface, and the conclusions thus reached are exhibited by geologic sections. As each economic mineral is definitely associated with certain geologic formations, the areal map, combined with the system of structure sections, is of fundamental importance with reference to the distribution of economic minerals, and is essentially an economic work. But so far as the presence and value of useful minerals has been discovered the work of the field geologist was made to apply directly to them. Special investigations were made of the bauxite deposits of Georgia and Alabama; of the coal seams of Alabama, Tennessee, West Virginia, Wyoming, and Montana; of the iron ores of North Carolina, Tennessee, New Jersey and Michigan; of a part of the corundum belt of North Carolina; of the phosphates of Florida and Tennessee; of an undeveloped petroleum field in Wyoming; of gold and silver in Montana, Wyoming, Colorado, and California; of fire-clay in Colorado; of artesian water in Colorado and in the coastal belt from New Jersey to Virginia; of building stone, cement rock, brick clay, and other structural material in Massachusetts, New York, New Jersey, Maryland, and Kansas.

OFFICE WORK.

In the office the geologists have made careful drawings of geologic and economic maps to be sent to the engraver. They have also constructed sections exhibiting the stratigraphy and geologic structure of the areas mapped, and have written chapters on local geology to accompany the maps. These chapters, although brief, are of peculiar importance, in that they not merely constitute the most authoritative account of the local structure and geologic history, but also are intended for the use of the owners of land in the several districts, many of whom are not familiar with the technical language of geologists. Great care is therefore taken with their phraseology, so that it may be at once simple and accurate.

Each district of areal work is found to illustrate some peculiar phase of geologic history or geologic processes, so that the careful study necessary to the delineation of the formations yields also a contribution to the philosophy of the science. It is through such contributions that the science is developed and the work of geologists everywhere is rendered more effective, and the formulation of such contributions is a recognized function of the geologic corps. This year, as in previous years, a large number of memoirs and essays have been prepared by geologists of the Survey, embodying such original contributions to the science of geology. Some of these appear elsewhere in this report, others are published as bulletins of the Survey, and a large number are printed by the scientific journals and scientific societies of the country.

A more detailed account of this work will be found in the accompanying administrative reports of the chiefs of parties, and a fuller abstract appears in the report of the geologist in charge.

PALEONTOLOGIC WORK.

The organisms whose remains occur in the rocks as fossils may be considered as representatives of the animal and vegetable kingdoms—the ancestors of living forms; or, since their characteristics have changed from age to age, they may be considered as the indices of geologic age. Paleontology thus has two sides, a biotic and a chronologic, and these are sometimes characterized as biologic paleontology and geologic or stratigraphic paleontology. Stratigraphic paleontology is of immediate service to the geologist, and for this reason it is given chief importance in the work of the paleontologic corps of the Geological Survey; but in a certain sense it is only the appplication of the principles of biologic paleontology, and for this reason the latter can not be entirely neglected. This year only a small amount of work has been accomplished in biologic paleontology.

The work of paleontologists in the interests of stratigraphy has been of two kinds: the identification of fossils collected by others, and the collection of fossils in the field in connection with personal stratigraphic studies. The geologist, mapping an area and studying the sequence of its rocks, gathers fossils at various horizons for the purpose of fixing definitely the geologic age of the different parts of a rock series. These fossils are submitted to the paleontologist, who identifies them so far as they are of species previously discovered, and informs the geologist what ages, periods, and epochs are indicated by them. If fossils are not easy to obtain, or if the stratigraphic problems are of such difficulty that large collections are important, the paleontologist is sometimes sent to the field, so that the work of collection may have the benefit of his technical skill.

With the more rapid prosecution of areal work the demands of geologists for the identification of fossils tend to increase, and much time has been bestowed on such identification during the year, but important studies have also been made in the field. One of these studies pertains to the Coastal Plain stratigraphy of Florida, another to the stratigraphy of the Potomac formation in the northern part of the Coastal Plain, and a third to the stratigraphy of the Coal-measures of the Appalachian bituminous field. In the Coal-measures a great series of rocks is characterized by rapid alternations of sandstones and shales, with rarer limestones. Nearly all of the beds are of limited horizontal extent, and each bed so closely resembles some other beds of the series in lithologic character that its tracing is a matter of difficulty. Notwithstanding the large amount of work which has been bestowed upon the coal-bearing rocks by official and unofficial geologists, there are many unsettled questions in regard to the comparative stratigraphy of neighboring districts, and the Survey has begun a detailed investigation of the fossil plants found at different horizons, for the purpose of bringing their evidence to bear on the problems of stratigraphy.

More detailed information in regard to the paleontologic work may be found in the report of the geologist in charge, and also in the admininstrative reports of the various paleontologists.

STATISTICAL WORK.

The work of the statistical division has continued under the able management of Dr. David T. Day, and its regular office staff has comprised three other persons. In addition to the material gathered by this staff, the division has, as heretofore, availed itself of the temporary services of leading specialists throughout the country. The volume of statistics for the year 1892, which was somewhat delayed by reason of the detail of Survey officers to the preparation of exhibits in the World's Fair, and also for the purpose of including data to be readily obtained at Chicago during the Fair, was published during this fiscal year, and the volume for the calendar year 1893 was prepared, proof-read, and printed. It will be issued as soon as bound.

The condition of the mineral industry of the United States during the year under review will long be a memorable one. As is well known, the previous year was one of very great activity in the production of minerals from familiar sources in this country. Our knowledge of the mineral resources has become so great as to tempt unexampled development of our mines, and, as is usual with such deposits, the minerals have been, as a rule, easy of production, and the need of careful and conservative mining has been little felt. Exploitation of readily accessible deposits was accompanied by great waste of low-grade material, or of such material as was not easily mined and marketed. In only a few instances in the country had the condition of more conservative mining with the utmost utilization of by-products and low-grade material been reached. The financial depression of the succeeding year has brought about a marked change, and every effort is now being made in the direction of conservative mining. The volume of product has largely fallen off, and its value in still larger ratio; but there has been a salutary change in the direction of more careful mining, with greater utilization of what was formerly waste material. It is not probable that within the next few years the country will again come up to the wonderful product of the year 1892. Nevertheless, for this great apparent loss there will be a measure of compensation in the lesson of economy and conservatism.

Details of the work of the division, together with a summary of the mineral production of the United States for 1893, may be found in the accompanying administrative report. Following is a compact summary:

Metallic products of the United States in 1893.

Products.	Quantity	Value.
Pig iron ... long tons..	7, 124, 502	$84, 810, 426
Silver ... troy ounces..	60, 000, 000	77, 575, 757
Gold ... do....	1, 739, 081	35, 950, 000
Copper ... pounds..	337, 416, 848	32, 054, 601
Lead ... short tons..	163, 982	11, 839, 590
Zinc ... do....	78, 832	6, 306, 560
Quicksilver ... flasks..	30, 164	1, 108, 527
Aluminum ... pounds..	339, 629	266, 903
Antimony ... short tons..	250	45, 000
Nickel ... pounds..	49, 399	22, 197
Tin ... do....	8, 938	1, 788
Platinum ... troy ounces..	75	517
Total value of metallic products ...	...	249, 981, 866

Nonmetallic mineral products of the United States in 1893.

Products.	Quantity	Value
Bituminous coal ... long tons..	114, 629, 671	$122, 751, 618
Pennsylvania anthracite ... do....	48, 185, 306	85, 687, 078
Lime ... barrels..	58, 000, 000	35, 960, 000
Building stone ...	...	33, 865, 573
Petroleum ... barrels..	48, 412, 666	28, 932, 326
Natural gas ...	...	14, 346, 250
Clay (all except potter's clay) ...	...	9, 000, 000
Cement ... barrels..	8, 002, 467	6, 262, 841
Mineral waters ... gallons sold..	23, 544, 495	4, 246, 734
Phosphate rock ... long tons..	941, 368	4, 136, 070
Salt ... barrels..	11, 816, 772	4, 054, 668
Limestone for iron flux ... long tons..	3, 958, 055	2, 374, 833
Zinc white ... short tons..	24, 059	1, 804, 420
Potter's clay ... long tons..	400, 000	900, 000
Gypsum ... short tons..	253, 615	696, 615
Borax ... pounds..	8, 699, 000	652, 425
Mineral paints ... short tons..	37, 714	530, 284
Fibrous talc ... do....	35, 861	403, 436
Asphaltum ... do....	47, 779	372, 232
Soapstone ... do....	21, 071	255, 067
Precious stones ...	...	264, 041
Pyrites ... long tons..	83, 277	275, 302
Corundum ... short tons..	1, 713	142, 325
Novaculite ... pounds..	...	135, 173

Nonmetallic mineral products of the United States in 1893—Continued.

Products.	Quantity	Value
Mica ... do ...	66,971	$88,929
Barytes ... short tons ..	28,970	88,506
Bromine ... pounds ..	348,399	104,520
Fluorspar ... short tons ..	12,400	84,000
Feldspar ... long tons ..	18,391	68,037
Manganese ore ... do ...	7,718	66,614
Flint ... do ...	29,671	63,792
Graphite ... pounds ..	843,103	63,232
Sulphur ... short tons ..	1,200	42,000
Marls ... do ...	75,000	40,000
Infusorial earth ... do ...	...	22,582
Millstones ...	...	16,645
Chromic iron ore ... long tons ..	1,450	21,750
Cobalt oxide ... pounds ..	8,422	10,346
Magnesite ... short tons ..	704	7,040
Asbestus ... do ...	50	2,500
Total value of nonmetallic mineral products ...	...	358,839,804
Total value of metallic products ...	...	249,981,866
Estimated value of mineral products unspecified *a* .	...	1,000,000
Grand total ...	...	609,821,670

a Including building sand, glass sand, limestone used as flux in lead smelting, limestone in glass-making, iron ore used as flux in lead smelting, tin ore, iridosmine, nitrate of soda, carbonate of soda, sulphate of soda, bauxite, and alum clays used by paper manufacturers

WORK IN CHEMISTRY.

The work of the chemical laboratory generally falls under the two heads of routine and investigation. The routine work consists of the analysis of rocks, ores, minerals, natural waters, etc., for the information of geologists. The investigation is directed toward the development of mineralogic and chemical science and the improvement of chemical methods. This year the work has been nearly all of a routine character, one hundred and ninety-two analyses having been made by the small corps of chemists, but a limited amount of attention has been given to investigation in two lines. Mr. Clarke has continued his researches on the constitution of the natural series of silicates, and Mr. Hillebrand has made some progress in the improvement of methods of rock analysis.

WORK IN HYDROGRAPHY.

The demands made upon the Survey for information concerning the water resources of the country exceed by far the limits of the accumulating supply of data. From all parts of the country, and especially from the West, come questions regarding the water supply, which for their answer require not only a broad knowledge of the topography, geologic structure, and climatic surroundings, but also a certain familiarity with local conditions governing the distribution and character of available waters. These inquiries are made by all classes of men; they come from farmers seeking to provide drinking water for domestic use, and from members of Congress having in view the best legislation concerning the utilization of streams flowing across State borders.

The General Government has the absolute title to nearly one-third of the area of the United States, excluding Alaska. Most of this vast area is open to settlement under the homestead law, and there exists a rapidly growing demand for land, a want whose intensity is shown by the mad race at the opening of the Cherokee strip. This anomaly—on the one hand a boundless area of fertile land free to all, and on the other a mass of would-be farmers vainly striving for a homestead—is explained by the peculiar conditions of water supply. The remaining public lands of the West are as a rule arid. There is only enough water for a small proportion of the rich soil, but we are still far from knowing the exact amount available and the best methods for its conservation and utilization. In order to throw light upon one of the many phases of the inquiry into the water resources, a thorough investigation was made into the present location and extent of the vacant land of the national domain. The results exhibit the remarkable degree to which settlement has followed the streams of the West and clustered about the foothills of the higher ranges, which, from abruptness of topography, insure perennial brooks and creeks. There is hardly a spring, rivulet, creek, or small river whose waters do not fructify and give value to farms. As a consequence the land is everywhere dotted with farms and ranches—fertile islands in a sea of desolation. Although so much water is utilized, yet it must not be inferred that all the water is employed. The great rivers, the storm waters, and the underground stores are hardly touched, and for the more complete development of the country it is necessary that attention be called to their value, or in some cases—as of underground supplies—to their probable existence.

Requests for information show by their scope a popular appreciation of the past work of the Survey, and in that respect they are encouraging; but at the same time they are embarrassing, in that it is assumed that this Survey has extended its investigations over the whole field when, as a matter of fact, the work has been carried on only in a restricted way and in a few of the more important localities.

Not only is the nation as a whole interested in the question of water resources as vital to the future of the public lands, but the older communities in the central and eastern portions of the country have each an immediate concern in the obtaining of exact information regarding water for domestic use and for power. With the rapid growth of towns and cities and the extension of agricultural operations the smaller streams, at least, become polluted, and to preserve public health, resort must be had in many cases to deep-seated or far-away waters for municipal supply. The economic and effective search for these waters involves the necessity of a knowledge of all of the factors above mentioned as entering into this hydrographic investigation. In the search for artesian waters especially, whether in the East or West, hundreds of attempts have been made and thousands of dollars wasted at spots where a thorough knowledge of the ground would forbid such expenditures. Each year this fact is being better appreciated, and in consequence developments in such lines, as well as in the utilization of water power, are held in abeyance for more complete knowledge, resting upon such facts as those which this division of the Survey is endeavoring to bring together.

The hydrographic work is not only intimately related to geology and topography, but also demands data from the records of climatic oscillations. It is, however, essentially a survey, and in its practical operations has been carried on most economically as a part of the topographic organization The results obtained during the past year have been in the line of those described in former reports and therefore will not need further comment. One of the most important results has been the completion of a preliminary map showing in a broad way the "run-off," or quantity of water which flows from the surface of the country. This is made in the conventional manner of the ordinary map of mean annual rainfall, but instead of showing the depth of precipitation in inches on the surface, it gives the depth in inches of that part of the precipitation which does not return to the atmosphere by evaporation, but flows over the surface to gather in streams. This map brings together in a condensed and graphic form all of the data concerning surface-water supply at present available. As knowledge increases and more facts are obtained this map will be perfected in detail.

COOPERATION WITH STATES.

By the legislature of the State of New York the sum of $24,000 was in 1893 appropriated for topographic work in cooperation with the U. S. Geological Survey. Such terms of cooperation were made as had been previously arranged with other States, the expense of the topographic mapping being divided between the State and the U. S. Geological Survey, and the Survey assuming direction of the work. Through this cooperation the topographic atlas of the State was advanced much more rapidly than would otherwise have been practicable.

Arrangements for cooperation were made with the State geologist of New York, and a considerable amount of detailed areal work was performed by one of the geologists of the national corps under the joint auspices of the two organizations.

Cooperation in geologic work with the State of New Jersey, which had been checked during the preceding year, was this year actively resumed, two geologists of the national Survey participating in the joint work.

By request of the State geologist of Georgia, a joint investigation was made of certain reported phosphatic deposits in that State.

In each of these cooperative investigations the expense has been shared by the State and national organizations, and it has been arranged that the results, topographic and geologic, shall be regarded as equally the property of both organizations.

WORK OF PUBLICATION.

EDITORIAL WORK ON BOOKS.

The editorial work has continued under the efficient direction of Mr. W. A. Croffut. A large amount of work has been accomplished, and at the close of the year the work of publication has been brought up to date.

I take great pleasure in acknowledging the indebtedness of this Bureau to the Government Printing Office for its cordial and intelligent cooperation.

Details of the work will be found in the accompanying administrative report, and a synopsis of the monographs and bulletins issued appears on subsequent pages.

WORK ON ILLUSTRATIONS.

In the Division of Illustrations nine draftsmen have been employed, under the competent direction of Mr. De Lancey W. Gill. The work of the division has included the drawing of illustrations for the various publications of the Survey, the preparation of photographs for reproduction by the half-tone process, the reading of proofs of illustrations, and the inspection of the entire edition of plates for our reports printed by private firms under contract with the Public Printer The division has also aided in the proof-reading of geologic and topographic maps During the year 1,642 drawings have been made, and engraved proofs of 850 drawings have been revised.

The photographic laboratory, which is under the immediate direction of Mr. J. K. Hillers, completes and makes prints from the negatives brought in by geologists in connection with their work, and makes a large number of photographs of manuscript maps to facilitate the reduction and compilation of topographic sheets. During this year 1,514 negatives have been made, and 11,152 prints.

More detailed information will be found in the accompanying report of the Division of Illustrations.

EDITORIAL WORK ON GEOLOGIC MAPS.

The plan for the publication of the Geologic Atlas of the United States has been of slow development. A study of the notations and technical methods used in the representation of geologic formations by the various State surveys and by the geological surveys of other countries served many years ago to show that the methods are inadequate, and that they fail to satisfy the peculiar conditions under which the Geologic Atlas of the United States is prepared. Not only is the area under survey by this Bureau larger than that surveyed by any similar organization, but the variety and complexity of geologic conditions is such that the number of separate formations to be mapped is far greater. To represent distinctly the vast number of American formations and exhibit their varied relations without confusion, a new system of notation was needed, and to perform the work with promptness and economy the most serious consideration must be given to the technical processes by means of which the notation was to be expressed. An outline of the notation finally adopted was published in the Tenth Annual Report, and much thought and experimentation have been since devoted to the development of practical details of productive processes. In this work I have received much assistance from various members of the corps, especially Messrs. G. K. Gilbert and Bailey Willis of the geologic force, and Mr. S. J. Kübel, chief engraver.

At the beginning of the fiscal year Mr. Willis was appointed editor of geologic maps, and he has since devoted nearly the whole of his time to the consideration of various questions arising in connection with the publication of the geologic folios. Under his efficient direction the selected patterns have been given such degrees of fineness and the selected colors have been given such degrees of strength as to secure the most pleasing artistic effect compatible with that distinctness which is necessary to the discrimination of the color areas. A descriptive essay designed to explain to the layman the various technical elements involved in topographic and geologic maps has been prepared, and important progress has been made in determining the scope and character of the individual descriptions which are to accompany the several sheets of the atlas. In these and in many other ways the plan of publication has been developed, and the sheets now in process of publication are being carried forward on well defined lines.

THE GEOLOGIC ATLAS OF THE UNITED STATES.

The Survey was organized for the object, among other purposes, of making a geologic map of the United States. In view of the vast extent of the country and of the detailed character of the proposed map, it was obvious in the beginning that it must take the form of an atlas, and as the operations of the Survey must be long continued, the atlas embodying the results should appear from time to time as the work progresses.

To the plan of this publication the Director gave prolonged consideration. The facts to be represented, covering the whole range of scientific and applied geology, were analyzed and classified with the aid of a conference of all the geologists connected with the Survey. A color scheme was elaborated and adopted; the size, form, and quality of the atlas were determined; the methods of engraving and printing were selected; the scope and style of the descriptions to accompany the maps were indicated; and a general explanation of the topographic and geologic facts to be set forth was prepared. The aim throughout was broadly to plan the beginnings of a publication which should present the scientific and economic results of the Survey in such form as to give them the highest practical and educational value.

PLAN OF PUBLICATION.

The Geologic Atlas of the United States is published as a serial, each part being a folio which describes the topography, geology, and mineral resources of a specific area. The atlas sheets are of approximately uniform size, each one covering, according to its scale of 1, 2, or 4 miles to an inch, about 250, 1000, or 4000 square miles. Each of these atlas sheets determines the specific area to be described in a folio of the Geologic Atlas. The publication will finally consist of more than 3,000 folios.

A folio is made up of topographic and geologic maps and descriptive letter-press, bound in a heavy paper cover. The contents vary according to the facts to be set forth. The essential elements are: the *description*, the *topographic* map, and the map of *areal geology*. To these may be added a geologic map conspicuously presenting the *economic resources*, a geologic map of *artesian water supply*, a geologic map of the *superficial formations*, a geologic map with *structure sections* showing the relations of rocks underground, a *columnar section* sheet giving the order of deposition and thicknesses of strata, and such other *special illustrations* as the interests of the region may call for.

The folios are printed in a library edition and a field edition. The two are identical in contents, but differ in the surface of the paper of the maps, the library edition being printed on a highly calendered surface, which gives the best effects to the patterns and colors, whereas the field edition is printed on paper of the same quality with a plain surface. The latter is more durable for folding and for exposure to moisture. A folio may be briefly described, following the order in which the reader, opening a copy before him, finds the sheets.

The cover.—The cover serves not only to protect the contents: it bears the title, an index map showing the position of the atlas sheet, and a list of the included sheets. It also shows the number of the folio in the series, so far as published. On the reverse of the cover, in front and back, is printed the general explanation of the maps, which is the same for all folios.

The description.—The subjects which may be discussed in describing the maps of a folio cover the range of geography and geology, but two considerations restrict the material to be presented in this connection and define its nature. The first of these is limited space; the second is the purpose of giving this publication the highest practical value possible by embodying in it all useful information in simple language. Scientific accuracy is not impaired, but the writings are addressed to the layman rather than to the scientist, there being opportunity in the other publications of the Survey for the presentation of the discussions which demand intimate knowledge of geology.

In geography and topography the description of a sheet is usually a verbal statement of the facts of relief, drainage, and culture which appear graphically in the map. Attention being called to the groups of topographic forms, they become distinct even to those who may not be accustomed to reading the symbols used upon the maps, and the reader may be prepared for a discussion of the development of the mountains and valleys and of other features of the landscape. In such a discussion the sciences of geography and geology unite to interpret the record of the past.

Accounts of the geology deal both with descriptions and interpretations. The descriptions relate to the lithologic character of the rocks, the places and manner of their occurrence, and their relations to each other. The interpretations state the probable sequence of events in the geologic history of the region. For the general reader little interest may, perhaps, attach to the simple descriptions, but when they are so written that each fact takes its place in the history, and that the series of facts tells the development of those changes which the continent has undergone, then the descriptions become interesting to all. Where the surveys are not sufficiently advanced to admit of broad generalizations from the observed facts, the descriptions have none the less a high value as sources of accurate information concerning the aspects, rocky structure, and mineral resources of the region. In agricultural districts the nature and distribution of the soils are usually stated.

The topographic map.—This map is prepared by the Topographic Division of the Survey, and is printed for the folios without change, except that a legend is added explaining the symbols used to delineate relief, drainage, and culture.

The map of areal geology.—The distribution of rock masses is brought out in this map, with special regard to their relations among themselves. Four great classes of rocks (superficial, sedimentary, igneous, and ancient crystalline rocks) are distinguished by as many groups of patterns. The superficial rocks are represented by dots and circles, the sedimentary rocks by parallel lines, the igneous rocks by rhomboidal and triangular figures, and the ancient crystallines by hachures in uniform but unsystematic arrangement. This distinction is fundamental in the scheme of representation.

The patterns are printed in color over the topographic map, and the use of color is determined by the requirement that the formations shall be clearly discriminated. A secondary consideration is that the maps shall present, so far as possible, a pleasing appearance. In the application of color, shade, and tint the greatest liberty is allowed for representing superficial, igneous, and ancient crystalline rocks. In general, however, brilliant colors are chosen for igneous rocks. Sedimentary rocks, on the contrary, are indicated by colors of fixed hues and of a dark shade. These colors, which are nine in number, corresponding to the nine periods from Algonkian to Neocene, inclusive, are used in the order of the spectrum to indicate successive periods of geologic history, as follows:

Neocene	Yellowish buff.	Devonian	Gray-blue-purple.
Eocene	Olive-brown.	Silurian	Gray-red-purple.
Cretaceous	Olive-green.	Cambrian	Brown-red.
Juratrias	Gray-blue-green.	Algonkian	Orange-brown.
Carboniferous	Gray-blue.		

The distinctions between formations of each period being obtained by printing patterns of lines of different widths, which produce contrasts of tint, it is essential that the colors themselves should be dark and heavy. Accordingly the sedimentary rocks, and generally, also, other formations, are represented by strong effects upon the map of areal geology. This is preeminently the geologic map, in which geologic facts are presented with emphasis, whereas topographic and economic features are less conspicuous. For districts in which the superficial formations are extensive and complex a map of the Pleistocene geology may be printed separately from that of the geology of the hard rocks.

The map of economic geology.—In many districts of the United States mineral resources, such as coal or iron, gold or other valuable metals, clays, sands, or useful stones, or artesian water, occur in relation to more or less extensive formations which are indicated on the map of areal geology. But these formations can not there consistently be made conspicuous. It is furthermore desirable to represent the facts of areal geology in their relations to topographic features, an object that is but partly accomplished in the first geologic map on account of the heavy coloring necessarily employed. Hence it has been found desirable to reprint the areal geology in lighter tints than those employed on the first map. This produces a copy of the map of areal geology in which the geologic distinctions are less marked, leaving the topography unobscured. This copy is then used as a base map on which stronger colors can be printed over the areas of special economic interest. Symbols for mines are also added. Thus the economic resources of a region are given emphatic representation.

The map of structural geology.—In many districts the arrangement of rocks is such that it is possible to determine the relations of masses underground from a survey of their relations at the surface. These inferences of underground structure are often of much importance in relation to mining or in boring for gas, oil, or water.

The representation of these relations is accomplished by printing structure sections across the map in a strip which is cut out just below the section line. Colors are used in simple relations, emphasis being given to formations of economic importance, and contours are omitted. In the sections and legend each formation is represented by an appropriate lithologic symbol.

Columnar sections.—The basis of geologic study is the order of succession of strata. The lithologic characters of strata suggest the conditions of their formation. These two classes of facts are stated in the columnar sections, together with information strictly relating to each separate formation.

Special illustrations.—The special illustrations may consist of large-scale maps of mining districts, detailed geologic sections, or reproductions of photographs of geologic phenomena. The selection of these illustrations is restricted, however, to subjects of peculiar interest.

METHOD OF PUBLICATION.

Original manuscripts.—The original copy of a geologic map consists of a printed topographic map, upon which the geologic boundaries and symbols have been drawn. The topographic sheet selected for this purpose should be perfect in all details and unmounted. The draftsman's work should be limited to outlining the areas of geologic formations, which should not be distinguished by water coloring, since it is important that the sheet should retain its precise size. In regions of specially complicated character a colored sheet may be advantageous if submitted with the original, but it is rarely necessary. Special data, such as are placed on the economic sheet and structure sections, are submitted in separate drawings. An important part of the original material, which should be prepared with special care, is the legend. This is a most concise statement of the facts to be represented and of their relations. Its arrangement determines, to a certain extent, the symbols, colors, and patterns to be used on the map, and its correctness is of great importance. The description of the region may or may not be submitted with the map.

The original drawings being received, it is usually necessary to discuss them with the author. This is facilitated by the association of the authors and editor in the Survey, and there is additional advantage as the work progresses in the intimate relation existing between the authors, editor, and chief engraver.

Engraving on copper.—All the atlas sheets prepared by the Survey are engraved on copper. For each topographic base three copperplates are used, and in preparing the geologic map a fourth is required. These constitute the permanent record of the surveys, and in event of a later edition following the first they may be revised or receive additional data. For the topographic map one plate is engraved with contour lines, a second with lines representing drainage, and a third with all roads, railroads, political boundaries, and names. They are known as the brown, blue, and black plates, respectively, because the impression of each plate is finally printed on the topographic sheet in the corresponding color.

For the geologic map an electrotype is made of the black plate of the topographic map, and the geologic boundaries, letter symbols, mine symbols, and all other data which are to appear in black in the geologic map are cut in the electrotype. Thus the black base of the geologic map is combined on one plate with the copy of the topographic black base, while the original black plate of the topographic map remains unchanged.

Proofs of the geologic black base are read in the Engraving Division, and the plate is corrected. Proofs of the revised engraving are then sent to the editor to be proof-read, and, if necessary, altered or amplified. In the progress of investigation, alterations of the map may become desirable at any stage of publication, but it is important that the final draft should be made at this time.

Being taken from the copperplate, this proof is called the plate proof. It is necessary to wet the paper to get a clear impression, and unequal shrinking results. The plate proof is, therefore, usually somewhat out of scale.

The lithographed base map.—The first step in the lithographic work consists of the preparation of the stone proof, which is so called to distinguish it from the plate proof. The stone proof consists of the geologic black base printed with the brown contour lines and blue drainage in nice adjustment on one sheet. Three stones, corresponding to the three copper plates, are required. One bears the impression of the geologic black base, one the contours, the third the drainage. They are combined by printing each in turn with a hand press. The stone proof is read in the Engraving Division; it is corrected, and revised proofs are sent to the editor. By him they are sent to the author.

In drawing a geologic map the geologist usually adjusts the boundaries to the contours and streams of the topographic base, for, away from roads, his observations are made with reference to elevations and water courses. But the engraver, in copying the geologic boundaries, necessarily fits them to the projection of the topographic map, the contours and drainage not being on the black plate. Hence if the black, brown, and blue impressions of the original base are not well registered, the correctly engraved boundaries will not fit the contours and drainage of a properly registered stone proof. The black boundaries will appear to be shifted to one side by an amount equal to the misregister of the original sheet in the opposite direction. In the stone proof this and any other errors of adjustment are corrected, and the final stone proof presents the geologic base combined with the topography, according to the best information available. The work is then ready for the preparation of the color stones for the different geologic sheets.

Lithographic color work.—All final map printing in the Geological Survey is done by lithographic processes, which print numerous distinct impressions on one sheet of paper with precise adjustment of outlines, so that different colors shall neither overlap nor fail to touch along adjacent areas. This adjustment is called the register of the sheet. The precision with which it is accomplished is a measure of the accuracy of the printing. Where many impressions are made on one sheet the attainment of good register involves incessant care, and the preliminary work of preparing the lithographic stones requires a high degree of skill.

The first step is the preparation of a "color guide" for the particular map in hand, by defining the colors and the areas of each color to be printed. The proper patterns must also be selected, and the area of each pattern must be indicated. This is done by the editor, who is controlled by the regulations of the color scheme, the requirements of distinctness and of color harmony, and, so far as they do not conflict with these considerations, the wishes of the author.

In order to facilitate the selection and definition of colors many hues have been printed. The chief engraver first selected a number of pigments, which were tested for permanency by exposure to a southern light for two months. Only the more permanent ones are used, but as they comprise various red, yellow, and blue pigments, their mixtures afford all desirable colors, shades, and tints. The patterns in which colors are printed had been given much consideration. When their general character had been determined from small samples the problem of preparing a large copperplate for each pattern, which should be uniformly engraved over the entire surface, still taxed the technical resources of the chief engraver. Patterns of parallel and those of intersecting lines were ruled by machine. But the multiplication of a sample pattern of hachures or dots required the aid of photolithography. The standard patterns being established, they were printed in appropriate colors, adapted to their uses on maps. Thus for the representation of sedimentary formations the flat tint and nine patterns of parallel lines, variously spaced, were printed in each of the nine somber colors selected respectively for the nine ages of the geologic time scale. For the representation of igneous rocks the flat tint and ten patterns, formed of triangular and rhomboidal figures, were printed in each of twenty-six brilliant colors and tints, which cover the range of the spectrum. In deference to the prevailing use of reds for volcanic rocks these hues form one-half of the series, but igneous rocks may be represented in any other bright tint. Crystalline, metamorphic rocks, and superficial or Pleistocene formations have not yet demanded representation in great variety in the printed maps. Color standards for them have accordingly not been prepared, but they are proposed.

The stone proof of a geologic map bears the complete legend, with color blocks. In making up the color guide for the lithographer the editor pastes a sample of the chosen standard color and pattern opposite each color block, with instructions, if any are needed. Furthermore, as many separate copies of the stone proof are colored by hand as there are distinct colors to be printed on the map, each sheet showing the areas to be printed in one color. Where several patterns are to be printed in the same color, as is frequently the case, the area of each pattern is distinctly colored out on a stone proof, with the areas of all the other patterns which are to be printed from the same stone.

The second step in the lithographic work is the preparation of as many stones as there are colors to be printed, one stone to correspond with each stone proof that has been colored out by hand. This, like the engraving and printing, is done under the direction of the chief engraver, and requires the services of men specially trained in drawing on lithographic stone. Upon the plane, smooth surface of the stone an "offset" or fugitive (temporary) impression of the geologic black base is made in a hand printing press. The outlines of that impression define the areas upon the stone from which a given color shall not be printed. These are covered for the time being by a coat of gum, and the desired pattern is transferred in black ink to the areas from which it shall be printed, which were left bare. In the simple case of one pattern this process requires only precision, but where several patterns must be placed upon one stone it involves many difficulties. The number of stones required for one geologic map, in addition to the three stones of the topographic base, varies from one to twenty. When in any case the requisite number has been prepared, the map goes to the third stage of the lithographic work—color proving.

Color proving consists of printing the appropriate tints in their proper relations upon the map. A number of stone proofs are provided; stone after stone is taken up by a pressman, working a hand press, and eventually a few "hand-proofs" of the complete map are turned out. The register of a hand proof is generally inferior to that of steam-press work, and the colors are not always closely matched with those selected. These conditions have to be considered by the editor, who proof-reads the color proof and generally submits it to the author..

When all corrections have been indicated, all patterns approved, and all colors, shades, and tints of the map considered, the color proof is returned to the Engraving Division for revision. Partial color proofs may be submitted, showing desired changes, and the work, when finally approved, is ready for printing on the steam press.

It is not proposed here to discuss the technical difficulties of fine lithographic work. The presses are run as fast as is consistent with good work, accuracy being preferred to speed, and it is usually estimated that it takes as many days to print an edition of 5,000 copies of one map as there are color stones for the sheet; that is, 5,000 copies can be printed at an average rate of one color per day.

Typographic work.—The folios of the Geologic Atlas contain explanations and descriptions, which are printed from type. The composition and printing are done in the engraving rooms of the Survey, and proofs are read by the editor of maps as well as by the editor of textual publications. Special attention is given to the subject-matter and form of statement of these descriptions, in order that they may be clear, concise, and prepared for the general reader.

The contents of a folio being printed, the sheets are arranged in paper covers, stitched, and bound by the Engraving Division, and they are then ready for distribution under the law.

PROGRESS IN PUBLICATION, 1893-'94.

The following is a list of the folios which have been received in original manuscript and carried on toward publication in the final form of the Geologic Atlas:

Alabama:
- Gadsden sheet. Plate proof received.
- Stevenson sheet. In process of engraving.

California:
- Jackson sheet. Stone proof received.
- Lassen Peak sheet. Preliminary edition printed.
- Marysville sheet. Original on hand.
- Placerville sheet. Final folio printed.
- Sacramento sheet. In press.
- Smartsville sheet. Original on hand.

Colorado:
- Anthracite sheet. Color proof read.
- Crested Butte sheet. Color proof read.
- Pikes Peak sheet. Color proof on hand.

District of Columbia:
- East Washington sheet. In process of engraving.
- West Washington sheet. In process of engraving.

Georgia:
- Ringgold sheet. Final folio printed.

Maryland:
- Annapolis sheet. Original on hand.
- Baltimore sheet. Preliminary edition printed.
- Brandywine sheet. Plate proofs received.
- Drum Point sheet. Original on hand.
- Fredericksburg sheet. Plate proof received.
- Prince Frederick sheet. Plate proof received.
- Sharps Island sheet. Original on hand.

Massachusetts:
- Belchertown sheet, superficial geology. In process of engraving.
- Belchertown sheet, under geology. Plate proof received.
- Berlin sheet. Original on hand.

Massachusetts—Continued.

Chesterfield sheet, surface geology. In process of engraving.
Chesterfield sheet, under geology. Plate proof received.
Granville sheet, superficial geology. In process of engraving.
Granville sheet, under geology. Plate proof received.
Greenfield sheet, superficial geology. Originals on hand.
Greenfield sheet, under geology. Plate proof received.
Hawley sheet, superficial geology. In process of engraving.
Hawley sheet, under geology. Preliminary edition printed.
Northampton sheet, surface geology. In process of engraving.
Northampton sheet, under geology. Plate proof received.
Palmer sheet, superficial geology. In process of engraving.
Palmer sheet, under geology. Plate proof received.
Pittsfield sheet. Originals on hand.
Springfield sheet, surface geology. In process of engraving.
Springfield sheet, under geology. Plate proof received.
Warwick sheet, superficial geology. Originals on hand.
Warwick sheet, under geology. Plate proof received.

Montana:

Livingston sheet. Final folio printed.
Three Forks sheet. Originals on hand.

New Jersey:

Plainfield sheet. Originals on hand.

New York:

New York State. Plate proof received.

Tennessee:

Chattanooga sheet. Final folio in press.
Cleveland sheet. Stone proof received.
Greenville sheet. Plate proof received.
Kingston sheet. Final folio in press.
Knoxville sheet. Original on hand.
Sewanee sheet. In process of engraving.

Virginia:

Estillville sheet. Color proofs received.
Staunton sheet. Experimental sheet printed in 1892.

West Virginia:

Harpers Ferry sheet. Final folio in press.
Pocahontas sheet. Original on hand.

United States:

Nine-sheet map. Plate proof received.

The explanation of the character and uses of the maps, which is printed on the inside of the cover of each folio, had been issued in a preliminary edition during the last fiscal year. In the recently published folios it appears with much modified statement and new illustrations. In its present form it is the result of much discussion, in which a number of geologists participated.

WORK IN ENGRAVING.

The division charged with the engraving of topographic and geologic maps continues under the competent direction of Mr.

S. J. Kübel. The funds appropriated for engraving were greater this year than last, and the establishment has been materially enlarged. On account of its experimental character a large share of attention has been given to the engraving and printing of geologic maps, and the chief engraver has cooperated with the editor of geologic maps in the organization and improvement of methods. Twenty topographic atlas sheets have been engraved, and editions of 330 topographic sheets have been printed. The details of the work are set forth in the accompanying report of the chief engraver.

In addition to the work of the Engraving Division, 49 topographic sheets have been engraved by private establishments under contract. The following table shows the distribution by States of the engraved topographic sheets:

Table showing the distribution by States of atlas sheets engraved to June 30, 1894.

State or Territory.	Wholly in State	Partly in State.	Scale	Contour interval.
				Feet
Alabama	10	6	1:125000	50-100
Arizona	11	5	1:250000	200-250
Arkansas	10	4	1: 62500 1:125000	20-50
California	25	3	1: 62500 1:125000 1:250000	25-50-100-200
Colorado	31	8	1: 62500 1:125000 1:250000	25-50-100-250
Connecticut	18	15	1: 62500	20
Delaware	....	1	1: 62500	10
District of Columbia	....	3	1: 62500	20
Florida	2	....	1: 62500	10
Georgia	5	12	1:125000	50-100
Idaho	9	1	1:125000	25-50-100
Illinois	13	9	1: 62500	10-20
Indiana	....	1	1: 62500	10
Indian Territory	....	4	1: 62500 1:125000	20-50
Iowa	17	5	1: 62500	20
Kansas	56	11	1: 62500 1:125000	20-50

Table showing the distribution by States of atlas sheets engraved to June 30, 1894—Continued.

State or Territory.	Wholly in State.	Partly in State.	Scale.	Contour interval.
				Feet.
Kentucky	7	7	1:125000	100
Louisiana	31	2	1: 62500	5
Maine	16	6	1: 62500	20
Maryland	13	12	{ 1: 62500 1:125000 }	20
Massachusetts	30	23	1: 62500	20
Mississippi	....	2	1: 62500	5
Missouri	24	9	1:125000	50
Montana	14	1	{ 1:125000 1:250000 }	50-100-200
Nevada	8	5	{ 1:125000 1:250000 }	25-50-100 200-250
New Hampshire	2	14	1: 62500	20
New Jersey	30	16	1: 62500	10-20
New Mexico	15	3	{ 1:125000 1:250000 }	25-50 100-200
New York	16	21	1: 62500	20
North Carolina	4	19	1:125000	50-100
North Dakota	4	3	1: 62500	20
Ohio	....	1	1:125000	100
Oregon	2	1	{ 1:125000 1:250000 }	25-50 100-200
Pennsylvania	23	9	1: 62500	20
Rhode Island	7	8	1: 62500	20
South Carolina	2	7	1:125000	50-100
South Dakota	5	3	{ 1: 62500 1:125000 }	20-50-100
Tennessee	10	21	1:125000	100
Texas	43	2	1:125000	25-50
Utah	13	4	1:250000	200-250
Vermont	4	7	1: 62500	20
Virginia	17	34	{ 1: 62500 1:125000 }	20-50-100
West Virginia	10	16	1:125000	100
Wisconsin	23	....	1: 62500	20
Wyoming, including Yellowstone National Park	5	....	1:125000	25-50-100

SYNOPSIS OF PUBLICATIONS, 1893-'94.

Following will be found an outline of the contents of monographs and bulletins published by the Survey during the fiscal year. There have also appeared the Thirteenth Annual Report, Parts II and III, the Fourteenth Annual Report, Part I, and the volume of Mineral Resources for 1892. The Mineral Resources for 1893 is nearly ready for issue:

MON. XIX.—THE PENOKEE IRON-BEARING SERIES OF MICHIGAN AND WISCONSIN. BY R. D. IRVING AND C. R. VAN HISE.

This report (534 pages) sets forth the chief scientific and economic characteristics of one of the most important mineral ranges.

The Penokee series proper is a succession of formations extending, with some breaks, from Lake Gogebic, Michigan, to Lake Numakagon, in Wisconsin, a distance of about 80 miles. It is a monoclinal series, its dips being universally to the north. The three formations making up the Penokee succession are the Quartz-slate member, the Iron-bearing member, and the Upper-slate member, and below these is the Cherty limestone formation. The series is sharply separated geographically from a crystalline complex to the south, called the Southern Complex. It is separated with equal sharpness from the Keweenaw series to the north.

Chapter I gives a history of the geological explorations in the Penokee district and a full summary of previous literature.

Chapter II treats of the Southern Complex. This consists of two main types of rocks—light colored, coarse grained granites and granite-gneisses, and dark colored, fine grained, finely laminated schists. In passing from west to east are found in order the Western granite, the Western green schist, the Central granite, the Eastern green schist, and the Eastern granite areas. The rocks of the Southern Complex are always completely crystalline. If any of them are of fragmental origin their present constitution gives no evidence of this. The contacts between the granite and the schists are eruptive, the granite being the intrusive rock. The schists are consequently older. Certain of the most laminated schists grade into rocks which are of distinctly eruptive types, and hence the only rocks in the Southern Complex the origin of which is known are igneous.

Chapter III treats of the Cherty limestone below the Penokee series proper. This formation, instead of being continuous, is found only at intervals, and varies in thickness up to 300 feet. It consists of cherty dolomitic limestone alternating with layers of chert. The Cherty limestone is a water-deposited sediment, but whether of chemical or organic origin, or of both, is uncertain.

Chapter IV treats of the Quartz-slate member. This member rests directly upon the Cherty limestone or upon the Southern Complex. It is a persistent, well characterized horizon, having an average thickness of about 500 feet. The Quartz-slate is always plainly clastic, and quartz is its prominent constituent, although other minerals, and especially feldspar, are not unimportant. Its uppermost horizon is a layer of pure vitreous quartzite.

Chapter V treats of the Iron-bearing member. This persistent formation, averaging about 800 feet in thickness, rests upon the vitreous quartzite of the Upper slate member. It now consists of three main types of rock, cherty iron carbonates, ferruginous slates and cherts, and actinolitic and magnetitic slates. The first of these is the orignal type of rock, and from it, by means of chemical changes, the second and third types, as well as the ore bodies, have been produced. The ore bodies are found in the lowest horizons of the formations, and are secondary concentrations.

They occur in V-shaped troughs, one side of the V's being the upper quartzite of the Quartz-slate, and the other diabase dikes. In the Animikie series, on the opposite side of Lake Superior, is an iron-bearing formation which has the same types of rock, derived from the same original form as in the Penokee series.

Chapter VI treats of the Upper slate member. This formation rests upon the Iron-bearing member. It has a maximum thickness of 12,000 feet, and has an extent east and west for many miles, although it is not so extensive as the Iron-bearing and Quartz-slate members. The formation is of clastic origin and consists mainly of graywackes and graywacke-slate. It is now locally altered by metasomatic changes, so that it has become a crystalline mica-schist.

Chapter VII treats of the eruptives. The Penokee eruptives are diabases, which structurally are of two classes, dikes cutting the formations, and interbedded sheets which are probably intrusives of the same age as the dikes. The eruptives are fresh in the slate members, but are much or completely altered in the Iron-bearing member, showing that environment, not age, is the important factor in the preservation of these rocks.

Chapter VIII treats of the Eastern area. In the eastern part of the district, as a result of contemporaneous volcanic action, the Penokee succession is disturbed, and associated with the ordinary detrital rocks are surface basic volcanic flows, and also greenstone-conglomerates and agglomerates. Consequent upon this volcanic disturbance the regular alternation of clastic and nonclastic members of the Penokee succession is much modified, so that the number and order of the formations here found differ from those in the remainder of the district.

Chapter IX treats of the general geology of the region. While the outcrops of the members of the Penokee series as a whole are gently curved, sharp flexures and faults are not common. One fault occurs at Bad River, another at Potato River, and perhaps one in the Eastern area. The base of the Quartz-slate member contains fragments derived from the Cherty limestone member, showing that between these formations there was an erosion interval. How great the time gap represented by this there is no means of judging, except that the chert of the limestone was certainly in its present condition at the time of the deposition of the Quartz-slate. The Quartz-slate, Iron-bearing, and Upper slate members form a conformable succession. Between the Penokee series proper and the Southern Complex there is a very great unconformity. Before the deposition of the Penokee series the Southern Complex had reached its present completely crystalline condition and was reduced nearly to baselevel. Between the Penokee series and the overlying Keweenawan is a second very considerable unconformity, sufficient to have removed in places the entire Penokee succession. After the erosion and deposition of the Keweenaw series the whole was tilted toward the north, so as to give the present monoclinal structure, after which the Eastern sandstone was deposited upon the upturned series in its present horizontal attitude. The Penokee series is limited on the east by the overlapping Eastern sandstone; on the west it was cut away by erosion before Keweenawan time, so that the Copper-bearing series rests directly upon the Southern Complex. The Penokee series proper is the equivalent of the Animikie, the Upper Original Huronian, and constitutes a part of the Upper Huronian of the Lake Superior region. The Cherty limestone is the equivalent of some part of the Lower Huronian. These two together are a part of the Algonkian, and the Southern Complex is Archean.

MON. XXI.—TERTIARY RHYNCHOPHOROUS COLEOPTERA OF THE UNITED STATES. BY SAMUEL HUBBARD SCUDDER.

This work consists of 206 pages and 12 illustrations. In the introduction the general features of the Tertiary insect fauna are discussed, and the characteristics of the group of beetles described in this monograph are more fully analyzed. The comparison of the recent and fossil Rhynchophora of America and of Europe shows "that the recent American Rhynchophorous fauna agrees better in its broad features with the Tertiary fauna of Europe than with the Tertiary fauna of America." The chief peculiarities of the American Tertiary fauna are the relatively great development of the Rhynchitidæ and Otiorhynchidæ, especially of the former, and the small representation of the Scolytidæ. The Curculionidæ, however, stand first in importance in both the fossil and recent faunas. The 193 species of Rhynchophora here treated are distributed among six families, as follows: Rhynchitidæ, 20; Otiorhynchidæ, 47; Curculionidæ, 100; Calandridæ, 10; Scolytidæ, 5; Anthribidæ, 11. All but 26 of the species are new to science and 30 of the 94 genera represented, together with the subfamily Isotheinæ, in the Rhynchitidæ, are also new.

All the material described, excepting two species, was obtained at four localities in the Rocky Mountain region, the well-known locality at Florissant, Colo., yielding 60 per cent of the species. The other three localities are Green River City, Wyo., the crest of the Roan Mountains in western Colorado, and the buttes bordering White River near the Colorado-Utah boundary. The collections from these three places have a large proportion of species in common, and the beds from which they come are regarded as strictly contemporaneous and as deposited in the same body of water—the Tertiary Gosiute lake of King. The Gosiute and Florissant faunas are totally distinct, having no species in common, and a very large proportion of the genera are different This dissimilarity in the faunas is considered too great to be accounted for by geographical separation only, especially in view of the fact that the Roan Mountains are about equally distant from Green River and Florissant, and it is more probably due to a difference in age, though it has not yet been determined which is the older. These deposits have heretofore been referred to the same horizon.

In the descriptive portion of the work the families and lower groups of the Tertiary Rhynchophora are discussed and the new genera and species are described and fully illustrated. Figures are also given of some of the previously described but unfigured species. In the larger genera "tables of species" are given, showing the distinctive characteristics of each species, and the same method is used in treating some of the higher groups.

The work ends with a systematic list of the species, showing their distribution and the number of specimens collected at each locality.

MON. XXII.—A MANUAL OF TOPOGRAPHIC METHODS. BY HENRY GANNETT

This work (300 pages) contains a description of the topographic work, instruments, and methods used by the U. S. Geological Survey, and is intended primarily for the information of the men engaged upon that work. The manual opens with an account of the various surveys made under the general and State governments and by private parties, and a description of the contributions made by these various organizations to a map of the country. This is followed by a statement of the plan of the topographic atlas made by the Geological Survey, its scales, contour intervals, size of sheets, contents, etc.

The work of map-making is classified into two parts, the geometric control and the sketching. The geometric control is classified as (*a*) Astronomic determination of positions, (*b*) Primary triangulation, (*c*) Secondary triangulation, (*d*) Traverse work, and (*e*) The measurement of heights. The principal instruments and methods used in each of these steps are quite fully treated of. Under *a* is described the method of determining longitude by a telegraphic comparison of local time and of latitude, by Talcott's method, with the zenith telescope. Under *b* is described the measurement of base lines with steel tapes, the expansion, character of signals, and the reduction of the work. Under *c* is described the plane table and its use. Under *d* is described the use of the small traverse plane-table and stadia measurements, while under *e* is described the measurement of heights by wye level, vertical angles, the aneroid and cistern barometers.

A chapter is devoted to sketching, including with this a brief outline of the origin of topographic forms.

Following the text is a body of tables for use in the various computations required in the work.

The book is illustrated with cuts of instruments and with specimen maps.

BULL. No 97.—THE MESOZOIC ECHINODERMATA OF THE UNITED STATES. BY WILLIAM BULLOCK CLARK.

All the known species of Echinodermata from the Mesozoic formations of the United States are systematically reviewed and fully described and illustrated in this work (207 pages; 50 plates). Of the 61 species described there are 5 of Crinoidea, 4 of Asteroidea, and 52 of Echinoidea. Thirty species are described as new either in this bulletin or in a preliminary paper by the same author. The Crinoidea are represented by 1 species each of Uintacrinus and Bourgueticrinus and by 3 species of Pentacrinus. The 4 species of Asteroidea are equally divided between the Ophiuridæ and the Stelleridæ. Among the Echinoidea the Regulares are represented by the families Cidaridæ, Salenidæ, Diadematidæ, and Echinidæ, while the Irregulares include species belonging to the Echinoconidæ, Cassidulidæ, Holasteridæ. and Spatangidæ.

The Jurassic strata have furnished 8 of the species; 1 of which may range down into the Trias, and the remainder are from the Cretaceous—16 species from the lower Cretaceous and 37 species from the upper.

The bulletin includes a full bibliography of works in which North American Mesozoic Echinodermata are treated, a table showing the geological distribution of the species, and an alphabetical index to the names that have been applied to these fossils by different authors.

BULL No 101.—INSECT FAUNA OF THE RHODE ISLAND COAL FIELD. BY PROF. S H SCUDDER

This bulletin (27 pages and 2 illustrations) describes a number of fossil insects found in the coal field of Rhode Island. They consist of Anthracomartus, the first discovered Arachnid in the Carboniferous deposits of the Eastern United States; a new genus of Neuropteroidea and one of Protophasmida, each very different from any forms hitherto found in this country, but rather allied to some from the rich Carboniferous beds of Commestry, in France, presenting new features of alliance between the Carboniferous faunas of Europe and America. All the species described are new to science and unknown elsewhere.

BULL. No 102.—CATALOGUE BIBLIOGRAPHY OF NORTH AMERICAN MESOZOIC INVERTEBRATA BY C B. BOYLE.

The first part (21 pages) of this bulletin is a list of works on the Mesozoic invertebrate fossils of North America, arranged alphabetically under the names of the authors. The record is intended to be complete to the end of 1890 and includes some papers published in 1891.

The second and principal part (pages 23–315) of the work is an alphabetical list of invertebrate species described from North American Mesozoic formations with references to date and place of publication, formation (distinguished simply as Triassic, Jurassic, or Cretaceous), and locality. A separate entry is made for each time a species has been described or figured. The total number of entries, including the bibliography, is 6,735.

BULL No. 103.—HIGH TEMPERATURE WORK IN IGNEOUS FUSION AND EBULLITION CHIEFLY IN RELATION TO PRESSURE BY CARL BARUS.

Many fundamental questions in physical geology depend on the behavior of molten rock producing magmas in their passage from the liquid to the solid state.

Thus it is obvious that, if the crust of the earth is sustained by matter which is either wholly or in part an excessively heated siliceous liquid on the verge of solidifying, the upheaval and subsidence of continents will in some measure depend on the modifications of volume which this liquid undergoes in passing through the change of physical state in question. In the nature of the case fusion within the earth is possible only under an enormous thickness of overlying rock, or, in other words, whatever fusion occurs must take place in defiance of the pressure of these strata. Nor is this consideration without importance, for it is known from thermodynamics that pressure very materially modifies the melting point of solids. Fusion in general is here particularly interesting, because we are justified in looking for large volume changes for relatively smaller ranges of temperature than occur elsewhere in either the liquid or the solid state.

It is the object of Bulletin 103 (57 pages; 12 illustrations) to give a succinct account of the character of the fusion phenomena in basic rock from actual experiments; to determine whether such fusion takes place with expansion or with contraction of volume; to measure numerically the amount of volume change produced and to compare it with the thermal expansion of the rock when liquid and when solid; and, furthermore, to determine in what degree the tendency to melt at a given temperature is modified by the pressure under which such fusion takes place, and therewithal (incidentally) to obtain data for the thermal capacity of white hot rock, liquid or solid.

This work at the very outset calls for accurate measurement of high temperature, and the first chapter of the bulletin is therefore devoted to revisional work in pyrometry. The standardization of such apparatus is usually made by the aid of known high-temperature boiling points and melting points. As these vary largely with the pressure of the atmosphere in which the boiling is conducted, an experimental study of this variation is made for pressures between zero and about one atmosphere. The results obtained for the best available boiling-point substances—mercury, sulphur, cadmium, zinc, bismuth—show a striking similarity of behavior when boiling points are taken at given pressures. The importance of these facts is set forth in the bulletin.

With the pyrometer thus newly standardized an elaborate series of measurements is then made on the contraction of diabase (taken as a typical rock) passing continuously from the liquid to the solid state. The apparatus (platinum tube charged with molten rock and provided with electric micrometry) and methods are fully discussed. The results prove definitely that rocks expand on melting and that their behavior is quite normal, thus settling one of the vexed questions in physical geology. The results also show the precise amounts of this expansion as compared with the thermal volume variations in the solid and in the liquid state separately.

Thereupon the thermal capacity of the rock, being next in the order of interest, is investigated for like conditions of white heat. The work is again carried out in detail, partly because of the intrinsic value of the data so obtained, but chiefly because these data are an essential factor in the thermodynamic expression for computing the variation of melting point with pressure.

Finally, utilizing these results as a whole, rock fusion, as depending on temperature and pressure, is discussed. It is found that the constants for molten silicates are nearly the same as the known values for more easily fusible laboratory material. With these data it is therefore possible to indicate the state of incipient fusion at different depths below the surface of the earth, and this is the purpose of the bulletin.

BULL. No. 104.—THE GLACIATION OF THE YELLOWSTONE VALLEY NORTH OF THE PARK BY W. H. WEED

This paper (41 pages, 5 illustrations) gives a detailed account of the glaciation of the Snowy Mountains and of the upper valleys of the Yellowstone, whose deposits show an unusual phase of alpine glaciation.

The evidence thus far gathered shows that a large body of ice, originating in the ice sheets of the Yellowstone National Park, pushed northward, filling the upper valleys of the Yellowstone and extending down that stream 36 miles north of the park boundary.

The high mountainous area east of the Yellowstone River, a large part of which is above 9,000 feet in elevation, was largely mantled by great snow fields and névés, above which the sharper summits projected as spires of rock, giving rise to great glaciers moving outward down the valleys in all directions, forming the Boulder glacier and many small streams flowing toward the valley of the Stillwater, while other glaciers filled the valleys south and east and became tributary to the Yellowstone glacier. The high country about Haystack Peak and Mount Douglas was the center of dispersion for this great ice field.

This evidence shows conclusively that there was no general system of confluent glaciers covering all the mountain ranges, but that even the greatest of these glaciers extended down the valleys a comparatively short distance and did not reach the general foothill country, while such considerable mountain masses as the Gallatin Range and the high and rugged peaks east of the Lower Canyon of the Yellowstone held only local glaciers which nestled in the cirques about the crest of the range or rarely extended a short distance down the valleys. The area covered by glacial deposits is indicated upon the accompanying map.

These glaciers were all of the alpine type and present many resemblances to those now existing in the Mount St. Elias alps. The largest valleys—the Yellowstone and Boulder—were occupied by trunk glaciers, which completely filled them and overrode their flanks, and received tribute from the lateral valleys where the ice bodies occupying them were large enough to reach the main valley. Throughout the entire field the higher peaks rose above the névé fields, though the high plateaus and broader mountain summits show considerable glacial abrasion and were unquestionably covered by moving ice.

The evidence establishing the former existence of these glaciers consists: (1) of the varied forms of glacial sculpturing—roches moutonnées, canyon-broadening, rock-scoring and polishing, and the formation of rock basins—(2) the various types of glacial deposits—bowlder trains, blocs perchés, the transportation of bowlders from lower to higher elevations, moraines and kames, and the associated trains of gravel forming the system of river terraces—(3) the formation of benches and terraces on hillsides, and (4) the cutting of canyons transverse to the mountain slopes and drainage in front of the glacier's termination. The striking contrast between glacial and nonglacial topography is splendidly exhibited in this field.

BULL. No. 105.—THE LARAMIE AND THE OVERLYING LIVINGSTON FORMATION IN MONTANA. BY W. H. WEED

Briefly summarized, this paper (68 pages, 7 illustrations) gives an account of a series of beds heretofore embraced within the Laramie, and covering the greater part of the State of Montana east of the Rocky Mountains. It is shown that a thickness of about 13,000 feet of sandstone shales and conglomerates belongs to three formations—the Laramie, the overlying Livingston, and the higher Fort Union beds. The Laramie is briefly described, and an account is given of the overlying series of strata composed of water-laid and assorted volcanic material, which are named the Livingston beds. Observations prove that these beds overlie the coal-bearing true Laramie rocks, and that they contain intercalated beds of true volcanic agglomerate. The entire Livingston formation is overlain by a great thickness of beds of fresh-water sandstones, of which the Crazy Mountains are formed, that are believed to be of Fort Union age. Stratigraphical evidence is presented to show that the Livingston beds are of post-Laramie age, yet older than and distinct from the Fort Union Eocene. Evidence is given showing an uplift with erosion during the accumulation of the Livingston beds and after the formation of the Laramie coal beds, and it is shown from the composition of the conglomerates and their relation to the consolidated ejectamenta of explosive volcanic eruptions, and from the nature of the overlying beds forming the Crazy Mountains, that we have undoubted proof of powerful dynamic movements, accompanied by eruptive activity following soon after the epoch of the coal-bearing Laramie, and marking the inception of that long period of volcanic action which continued with various interruptions into Pleistocene times and formed the great volcanic area of the Yellowstone National Park.

BULL. No. 106.—THE COLORADO FORMATION AND ITS INVERTEBRATE FAUNA. BY TIMOTHY W. STANTON.

The introductory portion of this paper (288 pages, 45 illustrations) includes a brief review of the literature of the subject, the definition of the Colorado formation, and a summary account of its geographic distribution, its stratigraphy, the local phases of its fauna, and its relations to other Cretaceous faunas. As here defined the Colorado formation includes the Fort Benton and Niobrara divisions of the standard Upper Missouri section, and is distributed over the area from Iowa to Utah and from Montana to New Mexico. The formation varies in thickness from 200 to about 1,500 feet in different regions, and it usually consists of shales and limestones, with the former greatly predominating, but in some parts of the area it includes considerable beds of sandstone. It is directly correlated with the Eagle Ford shales and Austin limestone of Texas, and it is regarded as approximately the taxonomic equivalent of the Turonian of Europe.

In the paleontologic portion the invertebrate fauna of about 150 species is treated systematically, giving a description and figures of each species (excepting Echinodermata). Thirty-nine species are described as new. With the exception of 1 crinoid, 1 echinoid, 2 species of Serpula and some fragmentary crustacean remains, this fauna is entirely molluscan, consisting of 83 species of Pelecypoda, 42 species of Gastropoda and 20 species of Cephalopoda.

BULL. No 107.—THE TRAP DIKES OF THE LAKE CHAMPLAIN REGION. BY J. F. KEMP AND V. F. MARSTERS.

In this bulletin (62 pages, 4 plates) Prof. J. F. Kemp and Mr. V. F. Marsters describe the trap dikes of the Lake Champlain region. The general distribution of the dikes is illustrated by maps. They pierce all the formations from the Archean to the Utica slates inclusive, and are formed by two strongly contrasted kinds of rocks; the one feldspathic porphyries and trachytes, which are called bostonite in this paper, the other dark basic rocks, which under the microscope are subdivided as diabases, camptonites, monchiquites, and fourchites. Both kinds occur closely associated in the same districts. In one instance the basic dikes are unquestionably the older.

The bostonite of that region has a prevailingly light color, which is usually creamy or brownish white, rarely like chocolate. The rocks have a general rough, granular feel, and a structure very like typical trachytes. Phenocrysts of quarts are rare, those of feldspar more common, and in one case large and abundant.

Under the microscope the rocks are at once seen to have a marked and characteristic trachytic structure, that is, the groundmass consists of small, lath-shaped crystals of orthoclase and perhaps also anorthoclase, which are not infrequently in fluidal arrangement, especially about the phenocrysts. No dark silicates whatever have been found in these rocks. In several cases remarkable breccias occur, composed of angular fragments of slate and quartzite, cemented by an igneous base of bostonite.

Of the basic dikes the true diabases are found principally, if not wholly, in the crystalline Archean areas.

The camptonites consist of brown basaltic hornblende, augite, plagioclase, magnetite, and occasionally a little intermingled glassy matter. In those considered typical there is no augite whatever. This is the case with two dikes, so far as the slides indicate. Usually, however, augite is also present, and may even predominate, marking thus a transition toward diabase. The minerals are markedly panidiomorphic, and the large hornblende and augites give at times a porphyritic character. The hornblende is the most conspicuous and attractive component of the rock. Rocks of this group were first clearly described from Campton, New Hampshire, but are now known to be rather widely distributed.

The monchiquites consist of olivine, augite, hornblende, biotite (one or all three of the last named), and a glassy base, and were so named from the Monchique mountains in Portugal, where such rocks were first described.

Fourchite differs from monchiquite in lacking olivine as an essential constituent. Augite is the principal constituent, and with it, at times, is considerable hornblende. Only one dike of this rock was found in the Champlain district.

The last three basic rocks in other regions are almost invariably associated with eleolite-syenite, and it is believed that their discovery in the Champlain district indicates that eleolite-syenite will yet be found in the Adirondacks.

BULL. No 108.—A GEOLOGICAL RECONNOISSANCE IN CENTRAL WASHINGTON. BY ISRAEL C. RUSSELL.

This is a report (108 pages, 20 illustrations) on a geological reconnoissance in the central part of the State of Washington, undertaken for the purpose of ascertaining to what extent the conditions there existing favor the project of obtaining artesian water for irrigation.

The region traversed embraced about 10,000 square miles, situated in the arid region east of the Cascade Mountains, and draining to Columbia River. A sketch map of the geology of this region is presented.

Crystalline rocks.—The oldest rocks in the area explored are schists, granites, and quartzites, occuring north of the Great Bend of the Columbia.

Kittitas system.—Resting on the eroded surfaces of the crystalline rocks is a series of sandstone and shales of early Tertiary age, which contain valuable coal seams. These rocks occur at the surface, to the west of the Columbia River and adjacent to the Cascade Mountains. The coal at Roslyn is in these rocks. The system is well exposed in the western part of Kittitas County, and hence is named provisionally the Kittitas system.

Columbia lava.—The principal formation in central Washington is a great series of lava sheets which have been outpoured in successive eruptions in such quantities as to completely conceal the relief of the land which was inundated by the fiery flood. This series of lava sheets is of such vast extent that it is the equivalent of some of the most important systems of sedimentary rocks. It extends south from Washington into Oregon and California, and east into Idaho. Its entire extent is unknown, but it is thought to cover not less than 200,000 square miles to an average depth of about 2,000 feet. It is the greatest lava sheet now known. The rock is principally if not wholly basalt, which came to the surface through fissures and was spread out in successive flows at intervals throughout a long period of time, as is shown by fossil forests inclosed between the layers at a number of horizons.

John Day system.—This system consists for the most part of unconsolidated sand and clay, together with large quantities of lapilli and volcanic dust, and has a thickness in some localities of over 1,000 feet. It is well exposed in the White Bluffs on the Columbia, and in Moxee, Wenas, and Kittitas valleys. The strata composing the system were deposited in a great water body called Lake John Day, which existed in late Tertiary times between the Cascade and Rocky mountains.

Glacial records.—After Lake John Day was drained and its sediments and the rocks on which they rest were uplifted into mountains and deeply eroded, a climatic change came which admitted of the existence of glaciers in the Cascade and Rocky mountains. A great glacier then filled the valley now occupied by Lake Chelan; another descended Okanogan Valley, and, crossing the Columbia, spread out a sheet of morainal material and thousands of huge bowlders over the northern part of Douglas County. Columbia River was dammed by these glaciers and escaped southward through Grand Coulée.

Lake Lewis.—The glaciers from the north ended in a large lake, the northern shore of which crossed the central part of Douglas County, and is known as Lake Lewis. Icebergs floating on this lake carried their freight of bowlders over the Great Plain of the Columbia and into many valleys opening from it.

After the deposition of the John Day system the rocks throughout central Washington and also over a vast region lying to the south were broken by a large number of fractures, some of them scores of miles in length, and the included blocks tilted in various directions so as to form monoclinal ridges or gently sloping table-lands. The displacement along many of these faults was between 2,000 and 3,000 feet.

Between the steep, narrow ridges there are level-floored valleys in which the John Day beds still retain their horizontal position. In a few instances the borders of the valleys have been raised so as to form artesian basins.

The conditions are briefly considered under which subsurface water may exist under pressure, so as to rise to the surface when wells are drilled. Certain popular fallacies relating to artesian wells are also pointed out.

A popular account is given of the geological formations and prevailing structure met with in each of the counties visited, and the conditions bearing on the question of subsurface water supply in each section are shown. As the region explored is one of a few within the United States concerning which there is but little information to be obtained from books, the sketch has been given something of an itinerary character. Some of the alkali lakes in Douglas County are described, and an analysis is given of the water of Soap Lake. The deposition of calcium carbonate through the action of low forms of plant life, from waters far below saturation, is briefly considered.

The last section of the paper is devoted to a summary of the conclusions reached in reference to the probabilities of obtaining artesian water in the region traversed. In general the conditions are such as not to favor the drilling of more wells.

The appendix contains a report by Mr. F. H. Knowlton on fossil leaves from the John Day system.

BULL. No. 109.—THE ERUPTIVE AND SEDIMENTARY ROCKS ON PIGEON POINT, MINNESOTA, AND THEIR CONTACT PHENOMENA. BY W. S. BAYLEY.

This paper contains 121 pages and 31 illustrations, and may be summarized as follows:

Pigeon Point is the northeastern extremity of Minnesota. It is one of a series of parallel points extending from Minnesota and Canada eastward into Lake Superior. Its backbone is a great east and west dike-like mass of a gray, coarse-grained rock that has always been called gabbro. This consists of phenocrysts of plagioclase in a diabasic groundmass of the same mineral, olivine and diallage, and consequently it is a diabase porphyrite.

Upon alteration the gabbro gives rise to phases that differ in their general aspect from the normal rock. The olivine and diallage pass into chlorite, biotite, and hornblende, and three varieties of the latter may be recognized. When compact brown amphibole originates in this manner the resulting rock resembles Irving's hornblende gabbros. The plagioclase of the gabbro changes into chlorite, quartz, and a reddish feldspar, of which the last two mentioned minerals are often in micropegmatitic intergrowths. The change of the plagioclase into red feldspar is in all probability a contact phenomenon.

The rocks through which the gabbro cuts are evenly bedded slates and indurated sandstones of Animikie age. They dip south-southeast at 15° to 20°, except at a very few places near the contact with other rocks, where they are more or less contorted.

Small dikes also intersect these sedimentaries. Their width varies from an inch or more to 60 feet, and their material is a nonolivinitic diabase that is often micaceous.

The most interesting feature in the geology of the point is the series of rocks usually occurring between the gabbro and the clastic beds. Beginning on the gabbro side the series comprises in succession coarse-grained red rocks, a fine-grained red rock that is sometimes porphyritic, and a well-marked belt of altered quartzites.

The fine-grained red rock has all the characteristics of an eruptive. It sends dikes into the contiguous bedded rocks, and consists essentially of a hypidiomorphic granular aggregate of plagioclase, anorthoclase, and quartz. The quartz and anorthoclase often form micropegmatite, while the plagioclase is in comparatively large grains, some of which have badly defined idiomorphic outlines. At a few places this red rock is porphyritic, with bipyramidal quartz crystals embedded in a red granophyric groundmass. The rock is similar to many of the augite-syenites described by Irving as occurring in the Keweenawan series, and is in structure and composition a quartz-keratophyre.

The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between these two. The variety nearest the gabbro differs but slightly from the basic eruptive. In addition to the gabbro components it contains a little quartz and red feldspar—constituents derived from the keratophyre. As the latter rock is approached the augite, olivine, and plagioclase disappear, while increased quantities of quartz, red feldspar, and brown hornblende make their appearance, and the rock becomes more and more like the fine-grained red rock. Finally the hornblende disappears and the keratophyre is reached. Since the intermediate rocks occur only between the gabbro and the fine-grained red rock, and since all gradations in composition between the two end members of the series are represented, the coarse-grained red rocks are regarded as contact products formed by the intermingling of the gabbro and the keratophyre magmas. In general peculiarities they are identical with some of Irving's orthoclase gabbros.

In the undoubted contact belt between the keratophyre and the unaltered slate and quartzites three zones are distinguished. In the exterior zone (that nearest the unaltered clastics) the rocks differ but little from the corresponding unaltered forms. The enlargements of the quartz grains, that are so marked a feature in the latter, have been lost, and with them all traces of the original fragmental character of the grains. The quartzes now interlock by irregular sutures. Bleached biotite, sericite, and chlorite are the only new minerals detected. The original regular bedding has not been disturbed.

In the middle zone of the contact belt the rocks are irregularly mottled in green and red. Sections made from the red portions of these rocks show rudely outlined bipyramidal quartz crystals in a matrix of globulitic red feldspar or of granophyre. The red feldspar, which is principally orthoclase, is much more abundant than it is in the rocks of the outer zone. The green portions contain but little feldspar. In composition and structure they are like the members of the exterior zone.

In the inner zone the rocks are of a uniform bright-red color, or they are bright red, spotted here and there with large, green, circular spots. In the spots the quartz grains interlock as in the least altered of the contact rocks. In the red groundmass, on the contrary, nearly all the quartz particles have the form of crystals, whose contours are generally broken by embayments of the feldspathic mass in which they lie. Even in this, the zone of most intense action, but few new minerals are discovered. Long acicular zircons often occur traversing two or three quartz grains, thus showing plainly their contact origin, and bundles of sericite are not infrequently scattered through the red feldspathic matrix.

From the above-mentioned facts it is concluded that the contact belt represents Animikie slates and quartzites that have been altered near their contact with an intrusive rock. The metamorphism of the quartzites has resulted simply in the recrystallization of the quartz and feldspar of the fragmental grains, with the addition, perhaps, of a little orthoclase.

Since, in several instances, the gabbro is in direct contact with the metamorphosed rocks, while the keratophyre is not to be found in the neighborhood, it is inferred that the former rock and not the latter was the cause of the contact action.

Inclusions of fragmentals in the gabbro and the keratophyre have alike suffered the same alterations as have taken place in the various members of the contact belt, with this difference, that quartzite inclusions in the basic rock are often surrounded by a rim of red rock, identical in all its properties with the keratophyre. This suggests that the keratophyre itself may be of contact origin.

The question that now arises is this: Is the keratophyre a genuine intrusive between the gabbro and its contact belt, or is it merely an extreme phase in the alteration of the clastic rocks by the gabbro?

The eighth chapter of the bulletin is devoted to the discussion of this question. The conclusion reached is that, in all probability, the keratophyre is of contact origin—that is, it was produced by the fusion of the slates and quartzites of the Animikie through the action upon them of the gabbro. The magma thus formed then acted in all respects like any intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda granite under certain circumstances, and under others as a quartz-keratophyre.

BULL. No. 110.—THE PALEOZOIC SECTION IN THE VICINITY OF THREE FORKS, MONTANA. BY A. C. PEALE.

This bulletin contains 56 pages and 8 illustrations. The area in which the section was made is adjacent to the junction of the three rivers—Jefferson, Madison, and Gallatin—which unite to form the Missouri River.

The structure of the region is complicated, and exhibits some features that are characteristic of a large part of the Rocky Mountains in Montana. The most striking feature noted is the rather common occurrence of overturned folds or isoclines. Isoclinal folds were noted by Dr. Peale in Montana in 1872, and in Colorado in 1873, but were then examined only in a general way.

In the folds described in the bulletin, the plane of the axis dips westward and northwestward—that is, the steep or overturned portion of the fold is on the west or northwest side of the synclinal basin. Some of the folds which begin as isoclines develop into normal anticlines, the trend of which is from N. 15° E. to N. 60° E. Inversion was not noticed in any of the folds with an east and west trend. The uplifts are isolated and their axial extent is limited. Over a large part of Montana this structure has resulted in the formation of numerous short ridges and ranges, giving rise to numerous lake basins filled with beds made up in most cases largely of wind-carried volcanic dust which was deposited on the surfaces of the lakes, or upon the surrounding country and afterwards carried into the lakes by streams.

Another point to which attention is called is the existence of an ancient pre-Cambrian shore-line, extending in a general westerly direction across the country about 10 or 12 miles south of the Three Forks. All of the area south of this line was in pre-Cambrian time part of a continental land mass, against which the sedimentary beds were pushed in the process of folding. The characters and stratigraphical position of the lowest Cambrian beds prove the general subsidence of the whole region prior to their deposition, and this subsidence probably continued throughout all Paleozoic time. The following is a section somewhat condensed:

Period	Formation	Thickness
		Feet
Carboniferous	Quadrant formation	350
	Madison formation	1,250
Devonian	Three Forks shales	135
	Jefferson formation	640
Devono-Silurian?		
Cambrian	Gallatin formation	835
	Flathead formation	415
Algonkian?	Belt formation	5,000+
Total		8,625+

The Belt formation referred to the Algonkian consists of an alternation of coarse micaceous sandstones and conglomerates, with beds of indurated argillaceous shales, and bands of thin-bedded, dark-blue, siliceous limestones which are slightly magnesian. They form a nonfossiliferous group of clastic beds made up largely of the debris of Archean rocks, sometimes slightly metamorphosed. From its stratigraphical position it could be only of lower Cambrian or of Algonkian age, and the absence of organic remains, the metamorphosed condition of the beds, and the existence of a nonconformity between them and the overlying quartzite led to their reference to the Algonkian.

The Cambrian rocks are divided into two formations, the Flathead formation, which is mainly arenaceous, and the Gallatin formation, which consists largely of limestone. The fossils found in the former come from the upper portion and are of middle Cambrian facies, while those from the Gallatin formation are, in the lower portion, correlated with the middle Cambrian zone of the Nevada and British Columbia sections, and those from the top resemble those which in the Eureka district pass into the base of the Ordovician. It is possible, therefore, that a part of the formation may have to be eventually referred to the Silurian, with perhaps a portion of the overlying beds now referred to the Devonian; this possibility is indicated by the use of the term Devono-Silurian. The major portion of the Jefferson formation, composed of massive dark colored magnesian limestone, is, however, undoubtedly of Devonian age, although a very meager collection of fossils was obtained from it, and these only from the upper part. The Three Forks shales, however, are highly fossiliferous. The first collection of fossils from this horizon was made by Dr. Peale in 1884. The list of fossils now numbers 39. Of the 23 forms specifically determined, 13 occur in the upper Devonian of the Eureka section, and 7 in the lower Devonian of the same, while 2 are common to both. Four are found in the lower Carboniferous of the Eureka district. Of those only generically determined, 5 closely resemble species from the Eureka Carboniferous, and all of the genera are found in the Devonian. Although there is a mingling of forms the preponderance is in favor of the Devonian age of the beds. The Carboniferous beds consists of bluish-gray or drab limestone, compact or fine-grained and even bedded, sometimes in massive beds, and often laminated, partly pure limestone, partly cherty, and in the upper part passing into quartzitic beds scarcely to be distinguished from those at the base of the overlying Mesozoic. The Madison formation consists mainly of massive-bedded limestones passing up into beds that contain a considerable amount of chert and jaspery nodules. Sixty species of fossils were collected from these beds. About 21 species occur in the lower portion, of which only 2 were not found in the middle and upper portions. From the upper portion 25 species were collected, only 5 of which were not obtained from the middle part.

Five species were found common to all the horizons, and 10 were common to both the Three Forks shales and Madison formations, and one of them. *Streptorynchus crenistria*, ranges from the Three Forks shales to the top of the Madison formation. Comparing the list with that from the Eureka section, 12 were found identical with the species from the Devonian of that section, 17 occurring in the lower Carboniferous and 7 in the upper Carboniferous. As a whole, therefore. the Madison limestones have a lower Carboniferous aspect, and they are so referred. After the deposition of these limestones shallower seas seems to have prevailed, and as a result there was a marked change in the character of the sediments. The quadrant formation, although containing limestones, is more arenaceous and argillaceous, especially in the lower beds. Ascending in the section, however, siliceous beds become more prominent, until the second ends in a series of thin-bedded quartzites and flinty limestones. Twenty species of fossils were obtained from the formation. Twelve of these were specifically determined, 7 of which were found also in the collections from the Madison formation, and only 1 passing down into the upper Devonian. Compared with the Eureka section 1 species is found only in the upper Carboniferous of that section; 7 are common to both the upper and lower Carboniferous there, and 2 pass down into the Devonian. There was an absence of most of the conspicuous forms of the Madison formation, and the beds are referred to the upper Carboniferous, partly upon stratigraphic grounds, and partly from paleontologic evidence.

A few of the eruptive rocks of the region are briefly described by Mr. George P. Merrill in an appendix to this bulletin.

BULL. No. 111.—GEOLOGY OF THE BIG STONE GAP COAL FIELD OF VIRGINIA AND KENTUCKY. BY M. R. CAMPBELL.

This bulletin (106 pages) treats of the stratigraphy and structure of a part of the Appalachian coal field in southwestern Virginia and eastern Kentucky. The area described lies in the Black mountains in Wise county, Virginia, and Harlan county, Kentucky, and is shown upon the Estillville atlas sheet, published in the Geological Atlas of the United States. The Carboniferous strata include those from the sub-Carboniferous limestone up to the Upper Coal Measures, and contain a number of workable coal veins in the Conglomerate series, the Norton shales, the Wise formation, and the Harlan sandstone. The thickness of coal-bearing strata from the base of the Conglomerate to the top of the Harlan sandstone is 5,030 feet. The report treats in detail of all coal exposures within the area, and coal veins are identified by careful stratigraphical and structural comparisons throughout the field. It is shown that the important beds in the western part of the field diminish in value toward the east, but that they are to some extent replaced by others which are themselves workable.

The strata are generally horizontal, but they are involved in minor flexures which form troughs and arches. These folds are not visible to the eye, but having been worked out barometrically are delineated upon a map, which must serve as a valuable guide in the development of mining operations. The report is also illustrated by a geologic map and by columnar and structure sections. It is the most careful contribution to our knowledge of any portion of the Appalachian coal fields since the publication of Dr. I. C. White's observations on the stratigraphy of the northern fields, or the work of the Second Geological Survey of Pennsylvania in the anthracite region.

BULL. No. 112.—EARTHQUAKES IN CALIFORNIA IN 1892. BY C. D. PERRINE.

This is a record (57 pages) of the earthquakes felt in California in 1892, including incidentally observations in other parts of the Pacific Coast. It is a continuation of the annual chronicle presented in Bulletins 68 and 95. Record is made of thirty-six shocks. The perturbations were measured at the Lick Observatory, and care was taken to estimate the different degrees of intensity.

BULL. No. 113.—REPORT OF WORK DONE IN THE DIVISION OF CHEMISTRY DURING THE FISCAL YEARS 1891-1893. BY F. W. CLARKE.

In this bulletin (115 pages), which is a partial report of work done in the Division of Chemistry during the fiscal years 1891–'92 and 1892–'93, there are seventeen distinct papers upon chemical and mineralogical topics. By Mr. F. W. Clarke there are two theoretical papers relative to the chlorites and micas, and by Mr. F. W. Clarke and Mr. E. A. Schneider jointly, two more describing experiments upon the constitution of the silicates. Mr. W. F. Hillebrand contributes four memoirs, one upon the rare minerals rowlandite and mackintoshite, one upon some zinciferous spring waters from Wisconsin, and two upon the oxides of uranium and thorium; Mr. W. H. Melville describes a remarkable nickel-iron from Oregon; Mr. L. G. Eakins gives an account of a new meteorite from Tennessee; and Mr. Schneider has three communications concerning colloids, and especially relating to colloidal silver. By Mr. H. N. Stokes there are four papers, three upon silicic ethers, and one upon a new amidophosphoric acid, and at the close of the bulletin there are a number of miscellaneous analyses of minerals, mineral waters, and so on. The bulletin covers a wide range of topics, and contains much new and original material.

BULL. No. 114.—EARTHQUAKES IN CALIFORNIA IN 1893. BY C. D. PERRINE

This is a record (21 pages) of the earthquake shocks in California noticed and reported in the calendar year 1893. It included also some reports of earthquakes in other localities on the Pacific Coast. There are thirty-six shocks recorded, but they merge into each other to some extent. Tracings were made in several places with duplex-pendulum seismographs.

BULLS. Nos. 115, 116, and 117.—GEOGRAPHIC DICTIONARIES. BY HENRY GANNETT.

Bulletins Nos. 115, 116, and 117 consist, respectively, of geographic dictionaries of the States of Rhode Island, Massachusetts, and Connecticut. These are designed to aid in finding any geographic feature upon the atlas sheets of the States which are published by the U. S. Geological Survey. They contain all the names given upon these sheets and no other name, and under each name is a brief description of the feature it designates and its location, while opposite to it is the name of the atlas sheet or sheets upon which it is to be found.

LIBRARY.

The library of the Survey contains 110,343 books, pamphlets, and maps, an increase during the year of 6,469 pieces. Of these acquisitions 1,106, or 19 per cent, were by purchase and the remaining 5,363, or 81 per cent, were by gift or exchange. Of the entire collection about 14 per cent have been purchased, and the remainder have been received by gift or exchange.

That the meaning of these figures may be clearly understood it is necessary to add that the library retains thoroughly its special character. It is distinctively a geologic library, with such additional material only as is required for the paleontologic, topographic, chemical, and other accessory divisions of the Survey. As a great body of geologic literature is contained in the transactions of learned societies and in the files of scientific journals, much attention has been given to securing full suites of these, and the library is now not merely one of the largest collections of geologic literature in the world, but is a most valuable reference library for all who have occasion to consult scientific serials.

Under the statute which provides that the publications of the Geological Survey may be disposed of by exchange and that the product of exchange shall become the property of the Survey, the enlargement of the library has been carried on pari passu with the distribution of publications; and the double purpose of distributing the results of the Survey's labors among the institutions devoted to scientific work throughout the world and of gathering the lore of those institutions for the use of the Survey has been accomplished in a manner that is highly satisfactory, fully vindicating the wisdom of the law.

The care of the library and the conduct of exchanges have remained in the skillful hands of Mr. C. C. Darwin.

The growth of the library during the past eleven years is shown in the following table:

Table showing in detail, by fiscal years, the contents of the library of the U. S. Geological Survey.

Year ending June 30—	Books.	Pamphlets.	Maps.	Total.
1883	8,714	6,400	1,000	16,114
1884	11,515	6,900	2,000	20,415
1885	14,712	11,200	4,000	29,912
1886	17,255	19,600	10,000	46,855
1887	19,501	26,100	12,000	57,601
1888	21,463	30,100	14,000	65,563
1889	24,300	34,100	17,000	75,400
1890	27,515	37,957	20,000	85,472
1891	29,635	41,217	22,337	93,189
1892	31,184	43,377	24,837	99,398
1893	32,342	45,717	25,815	103,874
1894	34,670	49,638	26,035	110,343

DISBURSEMENTS.

The fiscal business of the Survey has remained in charge of Mr. John D. McChesney, chief disbursing clerk, who, since the creation of the Survey, has discharged the duties of his office with marked energy and fidelity. A detailed statement of disbursements will be found in his administrative report. This statement is summarized in the following table:

FINANCIAL STATEMENT.

Amounts appropriated for and expended by the U. S. Geological Survey for the fiscal year ending June 30, 1894.

	Geological Survey.	Salaries office of Geological Survey.	Geological maps of the United States.	Total.
Appropriation for fiscal year 1894, acts approved March 3, 1893	$359,100.00	$35,540.00	$55,000.00	$449,640.00
Amounts expended, classified as follows:				
A. Services	265,626.43	35,279.87	27,002.50	
B. Traveling expenses	17,275.69		74.00	
C. Transportation of property	2,506.39		50.97	
D. Illustrations for reports	158.50			
E. Office rents	4,199.88			
F. Storage	1,138.48			
G. Correspondence	182.46		4.26	
I. Field subsistence	16,124.67			
K. Field and office supplies	25,449.20			
L. Instruments	1,042.32			
M. Field material	5,535.97			
N. Office furniture	283.20			
O. Books and maps	2,011.70			
P. Stationery and drawing material	683.53			
Q. Photographic material	2,342.73			
R. Laboratory material	192.34			
S. Engraving material and supplies			25,812.04	
T. Engraving maps (contract)			1,800.00	
U. Bonded railroad accounts: Passenger $917.20; Freight 398.07	1,315.27			
Total expenditures	346,068.76	35,279.87	54,743.77	436,092.40
Balance unexpended July 1, 1894	13,031.24	260.13	256.23	13,547.60
Probable amount required to meet outstanding liabilities	13,031.24		256.23	13,287.37

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, 1894.

ADMINISTRATIVE REPORTS.

REPORT OF MR. HENRY GANNETT.

U. S. GEOLOGICAL SURVEY,
EASTERN DIVISION OF TOPOGRAPHY,
Washington, D. C., June 30, 1894.

SIR: During the past year work in the Eastern Division of Topography has been carried on in fourteen States, namely: New Hampshire, Vermont, New York, Virginia, West Virginia, North Carolina, Tennessee, Michigan, Minnesota, North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. The area surveyed is 24,020 square miles, of which 22,395 square miles are on a scale of 1:62500, the balance (1,625 square miles) being on a scale of 1:125000. The contour interval accompanying the larger scale is, throughout, 20 feet; that accompanying the smaller is either 50 or 100 feet. Besides the above area, all of which is new work, there has been revised in Virginia, West Virginia, and North Carolina an area of 2,040 square miles, constituting two atlas sheets. The number of atlas sheets completed by this season's work is 106, of which all but two are on a scale of 1:62500, these two being the Hickory, in North Carolina, and the Wartburg, in Tennessee, which are on a scale of 1 : 125000. Besides these, several sheets have been surveyed in part.

The area surveyed is distributed as shown in the following table and on the map which constitutes Plate I of this report:

AREA SURVEYED.

States.	Scale of field work.	Contour interval.	Area surveyed.
		Feet.	*Sq. miles.*
New Hampshire	1:45000	20	110
Vermont	1:45000	20	150
New York	1:45000	20	5,250
North Carolina	1:63360	50	411
Tennessee	1:63360	100	1,214
Minnesota	1:31680	20	354
North Dakota	1:31680	20	2,060
South Dakota	1:31680	20	2,723
Nebraska	1:31680	20	8,140
Kansas	1:31680	20	935
Oklahoma	1:31680	20	2,673
Total			24,020

AREA REVISED.

States.	Scale of field work.	Contour interval.	Area surveyed.
		Feet.	*Sq. miles.*
Virginia and West Virginia	1:63360	100	1,000
North Carolina	1:63360	100	1,040
Total			2,040

ORGANIZATION.

The organization of this division has remained substantially the same as during the preceding year. The field work was organized in three sections, designated the Northeastern, Southeastern, and Central sections.

The Northeastern section includes all work done in States north of the Mason and Dixon line and east of Ohio; the Southeastern section, all work executed south of the Mason and Dixon line and the Ohio River and east of the Mississippi River; the Central section, all work in the Mississippi Valley east of the one hundredth meridian.

The sundry civil act, making an appropriation for the support of the Geological Survey, contained a provision requiring that $60,000 of the appropriation for topographic work be expended between the ninety-seventh and one hundred and third meridians in North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma. In its application to the work of this division, half of this amount, $30,000, was allotted to the region lying between the ninety-seventh and one hundredth meridians in the States above mentioned, and during the past season this work has constituted the field work of the Central section.

Besides these field sections, there has been maintained under control of this division a party for making astronomical observations in the field and for office computations.

During the field season there were 84 men, on an average, in the employ of this division, of whom 63 were engaged in professional work, consisting of topographers, assistant topographers, and field assistants, the remainder being the laboring force, such as cooks, drivers, and signal-men. During the winter there were employed in the office, on an average, 55 men.

NORTHEASTERN SECTION.

This section remained throughout the year in charge of Mr. H. M. Wilson, geographer. In it 5,510 square miles have been surveyed, thus completing 28 atlas sheets, with parts of two others. All these are on a publication scale of 1:62500, with a contour interval of 20 feet. Nearly all the work of this section has been within New York State.

In the preceding winter the State of New York made an appropriation of $24,000 for cooperation with the U. S. Geological Survey in the preparation of a map of its area. This appropriation was put in charge of the State engineer, Mr. Martin Schenck, and articles of agreement for cooperation in the prosecution of the work were drawn up and signed, the conditions being practically the same as those which obtained in the joint surveys of Massachusetts, Rhode Island, and Conneticut. Under this agreement work has progressed rapidly and efficiently, and to the entire satisfaction of the State officers.

Of the area surveyed in this section (5,510 square miles), 5,250 square miles are comprised within the State of New York, the remainder being in New Hampshire and Vermont.

The number of square miles surveyed per party per day ranged from 2.6 up to 6.9. This excessive range is accounted for partly by differences in the degree of difficulty of the country and partly by differences in the experience and capacity of the surveyors. The rate at which traverse work has been carried on, measured in linear miles per man per day, ranged from 5.1 up to 18.4 miles. The number of locations made by triangulation ranged from 0.3 up to 4.6 per square mile. The number of linear miles of traverse per square mile of area ranged from 1 up to 3.7, and the number of elevations measured in each square mile ranged from 7.5 up to 22.4.

The area surveyed by this section is distributed as follows among the various parties and fields of work:

Chief of party.	Atlas sheets.	Area.
		Sq. miles.
Barnard, E. C	Rouse Point, Plattsburg, Moores	520
Sutton, Frank	Buffalo, Tonawanda, Niagara Falls, Rochester, Wilson	708
Jennings, J. H	Syracuse, Oneida, Chittenango, Oriskany	820
Cummin, R. D	Elmira, Ithaca	610
Lovell, W. H	Watertown, Sacketts Harbor, Pulaski, Stony Island, Cape Vincent	660
Chapman, R. H	Willsboro, Ausable, Lake Placid	325
Clark, E. B	Amsterdam, Fonda	282
Hyde, G. E	Cambridge, Fort Ann, Whitehall	634
Beaman, W. M	Catskill, Rhinebeck	445
Muldrow, Robert	Crawford Notch	110

These ten parties were placed in the field on or about the 8th of May, and they worked continuously until the close of the season, concluding their work in the latter part of October or early in November. The areas in which they worked are indicated by the names of the atlas sheets in the above table. Toward the close of the season some changes of personnel were made in order to insure the completion of certain atlas sheets.

Much primary triangulation available for the control of topographic maps has been executed within New York State. The work of the U. S. Coast and Geodetic Survey extends up the Hudson River, across to Lake Champlain, and down the lake to the Canadian boundary; that of the Lake Survey extends along the shores of lakes Erie and Ontario; and that executed by the New York State survey under Mr. J. T. Gardiner extends from the Hudson to Lake Ontario and southward across the middle of the State to the Pennsylvania boundary. This triangulation went far toward supplying the necessary primary control, but there remained extensive areas in the northern, southeastern, and southwestern parts of the State which were without control and in which it was necessary to execute triangulation prior to commencing topographic work. Moreover, within the areas covered by these systems of triangulation there were numerous sheets upon which no points had been located. It was necessary therefore in many cases to extend triangulation beyond the limits of the former work, and also to interpolate points within bodies of triangulation. Mr. S. S. Gannett was detailed for this work, with Mr. B. C. Washington, jr., as his assistant. He took the field in July, going first to the northeastern part of the State to extend the triangulation of the U. S. Coast and Geodetic Survey westward from Lake Champlain. Later he went to the neighborhood of Watertown and extended the triangulation of the Lake Survey so as to include atlas sheets to be surveyed. Upon the completion of this work he went to the neighborhood of Buffalo and extended triangulation southward from a base furnished by points of the Lake Survey. His last work consisted of the extension of the triangulation from the Hudson River belt of the U. S. Coast and Geodetic Survey westward into the Rosendale sheet. Altogether, during the season, Mr. Gannett selected and occupied thirty-five triangulation stations.

To Mr. E. C. Barnard, with two assistants, were assigned three sheets in the northeast corner of the State, known as Rouse Point, Moores, and Plattsburg. The country is rolling and in large part heavily forested, thus presenting considerable difficulties. This party completed these sheets and left the field in the latter part of October.

To Mr. J. H. Jennings were assigned two sheets, known as the Syracuse and Oneida, in the central part of the State. His work progressed with great rapidity, owing in part to favorable natural conditions and in part to Mr. Jennings's ability, so that, as the outcome of the season's work, he completed not only these sheets but two others lying east of them.

To Mr. Frank Sutton, with two assistants, was assigned the region about Niagara Falls and Buffalo, comprising what are known as the Buffalo, Tonawanda, Niagara Falls, and Wilson sheets. This region is, so far as its natural features are concerned, very easy to survey, but the complicated cultural features presented by the cities of Buffalo and Niagara Falls more than offset the facilities afforded by nature. This party, however, completed the area originally assigned it, and in addition surveyed the Rochester sheet.

To Mr. R. D. Cummin, with three assistants, were assigned the Elmira, Ithaca, and Watkins Glen sheets, in the southern part of the

State. The first two of these sheets were completed, when it was deemed advisable not to commence the survey of the Watkins Glen sheet, but to detach Mr. Cummin for the purpose of assisting in the completion of the Fonda sheet, in the Mohawk Valley.

To Mr. W. H. Lovell was assigned an area about the city of Watertown, near Lake Ontario. This area comprises the sheets known as Watertown, Sacketts Harbor, Pulaski, Stony Island, and Cape Vincent. By continuing work into November, Mr. Lovell succeeded in completing this entire area.

To Mr. Robert H. Chapman were assigned three sheets in the Adirondacks, known as the Lake Placid, Ausable, and Willsboro sheets. The last two sheets were completed and the southern half of the Lake Placid. Then, the season being far advanced, it was deemed inadvisable to attempt to complete the sheet, and the party was recalled from the field.

To Mr. E. B. Clark, with two assistants, were assigned the Amsterdam and Fonda sheets, in the Mohawk Valley. Mr. Clark met with difficulties in the prosecution of his work, which delayed him so that he was able to complete only the Amsterdam sheet and about one-half of the Fonda sheet.

To Mr. George E. Hyde, with two assistants, were assigned the Cambridge, Fort Ann, and Whitehall sheets, along the eastern border of the State, and with some assistance near the close of the season, he completed these three sheets.

To Mr. W. M. Béaman, with one assistant, were assigned the Catskill and Rhinebeck sheets. He succeeded in finishing these sheets, with some outside assistance toward the close of the season.

To Mr. Robert Muldrow was assigned the completion of the Crawford Notch sheet, in New Hampshire. This work occupied Mr. Muldrow but a short time, and during the remainder of the season he assisted in completing the Catskill sheet.

SOUTHEASTERN SECTION.

This section has remained in charge of Mr. Gilbert Thompson. During the past season an area of 1,625 square miles of new work has been surveyed, besides which 2,040 square miles have been thoroughly revised. The new work has been done in the States of North Carolina and Tennessee, and the work of revision has been in Virginia, West Virginia, and North Carolina.

During the season of 1892 the northern portion of the Hickory sheet, North Carolina, was surveyed by Mr. L. C. Fletcher. To complete this sheet Mr. Merrill Hackett, with one assistant, was sent to the locality. His party commenced work upon it on July 18 and completed it early in September, having surveyed 411 square miles. Upon its completion he was directed to devote the remainder of the season to the revision of the Morganton sheet, which adjoins it on the west.

His party was recalled from the field on October 1, after having revised 110 square miles of this sheet.

To Mr. A. E. Murlin, with three assistants, was assigned the Wartburg sheet and such part of the Livingston sheet, Tennessee, as the season would permit. Mr. Murlin commenced work on July 17 and worked continuously until November 15. His party surveyed 1,214 square miles, completing the Wartburg sheet and about one-fourth of the Livingston sheet.

The revision of the Nantahalah sheet, North Carolina, was commenced during the season of 1892. During the past season the revision of this sheet has been carried to completion by Mr. Charles E. Cooke, with one assistant. He commenced work on July 15 and closed on October 14, having revised 930 square miles.

The revision of the Tazewell sheet, Virginia, was intrusted to Mr. Hersey Munroe, with one assistant. He commenced work on July 10, and although much delayed by sickness, succeeded in completing the work on November 7, having revised an area of about 1,000 square miles.

CENTRAL SECTION.

This section has remained in charge of Mr. J. H. Renshawe. Work has been prosecuted in Minnesota, North and South Dakota, Nebraska, Kansas, and Oklahoma. An area of 16,885 square miles has been surveyed, all on a scale of 1:62500, with a contour interval of 20 feet. This area completes 75 atlas sheets. The results are summarized in the following table:

Chief of party.	State.	Area.
		Sq. miles.
Baldwin, H. L	Minnesota	354
Manning, V. H	North Dakota	2,060
Harrison, D. C	South Dakota	2,723
Peters, W. J	Nebraska	3,608
Towson, R. M	Nebraska	2,179
Wallace, H. S	Nebraska	1,353
Seely, F. H	Kansas	935
Blair, H. B	Oklahoma	2,673

For the control of the work in the Dakotas and Oklahoma it was necessary to run lines of primary traverse, additional to those run during the season of 1892. Mr. George T. Hawkins was detailed in July for this work and furnished with the requisite number of rodmen and chainmen. He commenced work in North Dakota on July 20, running first a line along the Northern Pacific Railroad from Cleveland to Valley City, a distance of 54 miles; then from La Moure to Edgeley, 22 miles; then from Edgeley south to Aberdeen, S. Dak., 63 miles. He then ran from Ipswich, through Groton and Dolan, to

Rockham, a distance of 123 miles; then from Redfield through Wolsey to Pierre, a distance of 142 miles, connecting at Pierre with the triangulation of the Missouri River Commission. The total distance thus traversed in the Dakotas is 404 miles.

Upon the completion of the work in the Dakotas, Mr. Hawkins was ordered to the upper peninsula of Michigan for the purpose of supplying control in a part of the iron region which had been mapped in previous years. For this purpose he ran a circuit commencing at Champion in the Marquette district and embracing this region. This line has a length of 115 miles.

Mr. Hawkins was then ordered to Oklahoma for the purpose of extending the primary control in that area of work. He ran from Oklahoma City west to El Reno, 30 miles, thence northward to the north line of Oklahoma, on the Chicago, Rock Island and Pacific Railroad, and thence across the country, there being no railroad available, to Santa Fe, near Guthrie, where he connected with his line of the year before. The total distance measured in Oklahoma was 114 miles, and the total distance traversed by his party during the season was 633 miles.

In the prosecution of his work Mr. Hawkins has observed for azimuth upon Polaris at intervals from 10 to 12 miles. At intervals of 5 to 6 miles he connected with township or section lines of the Land Office surveys, noting not only the points of intersection with the land surveys but the azimuth of the lines he crossed, thus forming close connection between his work and the land system.

For the inception of work in northern Minnesota, Mr. Harry L. Baldwin and two assistants were ordered to the field in July. Work was soon afterward commenced in the neighborhood of Duluth, and the Duluth sheet was finished in September. The party was then moved to Tower, in the Vermilion iron range, and work was prosecuted in that neighborhood until the close of the season. Altogether an area of 354 square miles was surveyed, including the 204 square miles which are comprised in the Duluth sheet.

Work in North Dakota was continued during the past season by Mr. Van H. Manning, with two assistants. This party took the field early in June and prosecuted work continuously until the end of October. The product of the season's work was 10 atlas sheets, comprising 2,060 square miles.

The work in South Dakota was continued by Mr. D. C. Harrison, with one assistant. This party took the field in June and worked continuously until the middle of October. The area surveyed was 2,723 square miles, completing 13 atlas sheets.

Work was prosecuted during the past season in Nebraska by three parties, in charge, respectively, of Mr. H. S. Wallace, Mr. Wm. J. Peters, and Mr. R. M. Towson. Mr. Wallace took the field alone early in July and worked unassisted until the 1st of September, when he was joined by Mr. F. H. Seely, who had completed the area in Kansas assigned to him. With Mr. Seely's assistance the party completed by the end of October, when field work was discontinued, an area of 1,353 square miles, comprising 6 atlas sheets. This area lies in the eastern part of the State, including Douglas and adjacent counties and extending across the river to include Council Bluffs and the bottom lands to the north and south.

The party under Mr. Peters took the field early in June and worked continuously until the end of October. The field of work lay mainly in middle Nebraska, including the lower course of Loup Fork and the Platte as far east as the ninty-seventh meridian. With the aid of three assistants, Mr. Peters surveyed an area of 3,608 square miles, comprising 16 atlas sheets.

The party under Mr. Towson worked in the southwestern part of the State, taking the field in June and working continuously until the end of October. With the aid of two assistants, Mr. Towson surveyed 3,179 square miles, comprising 14 atlas sheets.

Mr. F. H. Seely was sent to the field in Kansas early in June for the purpose of completing 4 sheets in the northern-central part of the State. Lines of level had been run over these sheets during the previous season by Mr. Towson, preliminary to sketching the topography. Mr. Seely's work consisted in supplementing these lines of level by aneroid measurements and in sketching the topography. He commenced work about the middle of June and completed the 4 sheets by the end of August. The area comprised was 935 square miles.

For the extension of the mapped area in Oklahoma, Mr. H. B. Blair, with three assistants, was sent to the field early in June. The party worked continuously until late in November and completed 11 sheets, comprising 2,673 square miles. This surveyed area lies east, west, north, and south of that surveyed during the season of 1892.

OFFICE WORK.

During the winter the surveying force has been engaged, as usual, in transferring the plane-table sheets and in inking and lettering the original maps. The work has gone on rapidly and efficiently, and all the work of the past season has been put into shape and made ready for the engraver.

Messrs. S. S. Gannett, G. T. Hawkins, and B. C. Washington have been occupied in the reduction of triangulation and of primary traverse lines.

Among the minor and incidental pieces of work which have been undertaken and completed during the past year may be mentioned the preparation by myself of a manual of surveying, detailing the methods employed in this organization, and the preparation and publication of geographic dictionaries of the States of Massachusetts, Rhode Island, Connecticut, and New Jersey, the maps of which States have been completed. There is in course of preparation and nearly completed a compilation of geographic positions in the United States, whether determined by astronomic means or by triangulation, including those determined by National and State organizations and by private parties. It is intended to include in this all positions which are known to be of a sufficient degree of accuracy for controlling maps upon a scale of 1:125,000.

Very respectfully, yours,

HENRY GANNETT,
Chief Topographer.

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

REPORT OF MR. A. H. THOMPSON.

U. S. GEOLOGICAL SURVEY,
WESTERN DIVISION OF TOPOGRAPHY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of topographic work west of the one hundredth meridian for the year ending June 30, 1894.

In accordance with plans submitted to you and approved by the Secretary of the Interior, field work was prosecuted during the year in the States of California, Colorado, Idaho, Oregon, South Dakota, Texas, Washington, and Wyoming, and office work in the general office at Washington, D. C., and in field offices at San Francisco and Los Angeles, Cal.; Portland, Oreg.; Seattle, Wash.; and Boise, Idaho.

ORGANIZATION.

For administrative supervision and management the work of this division was organized into seven topographic sections, the central part of California constituting the first, the southern part of California the second, Colorado and South Dakota the third, Idaho and Oregon the fourth, Texas the fifth, Washington the sixth, and Wyoming the seventh. Each of these sections was placed under the immediate direction of a chief, who, in addition to the supervision of the work under him, was assigned a certain definite part thereof, usually triangulation.

A hydrographic section was also organized for the purpose of measuring the flow of streams in the arid region west of the one hundredth meridian.

PERSONNEL OF SECTIONS.

California, Central.—Mr. Willard D. Johnson, topographer, was continued in charge of this section. Mr. R. B. Marshall, topographer, and Mr. Stuart P. Johnson and Mr. W. H. Otis, assistant topographers, were assigned as his assistants to take charge of parties. Mr. Selden

B. Hooper was also employed as field assistant. On February 1, 1894, Mr. Stuart P. Johnson resigned from the Survey, Messrs. Marshall and Otis continuing to the close of the year.

California, Southern.—This section was continued under charge of Mr. Arthur P. Davis. Mr. W. S. Post, topographer, and Mr. Paul Holman and Mr. Thomas Gerdine, assistant topographers, were assigned as his assistants; and on November 1 Mr. C. B. Green, assistant topographer, was transferred from the Texas to the Southern California section for service during the remainder of the year. No other changes occurred during the year.

Colorado-South Dakota.—Mr. E. M. Douglas, topographer, was continued in charge of this section. Mr. R. C. McKinney, Mr. R. A. Farmer, topographers, Mr. W. B. Corse, Mr. T. M. Bannon, Mr. George O. Glavis, and Mr. J. Macfarland, assistant topographers, were assigned to him as assistants. No change in personnel occurred in this section during the year.

Idaho-Oregon.—Mr. W. T. Griswold was continued in charge of this section, with Mr. E. T. Perkins, jr., topographer, and Mr. A. C. Barclay, assistant topographer, as assistants. No change in personnel occurred during the year.

Texas.—Mr. R. U. Goode, topographer, was continued in charge of this section. Mr. R. O. Gordon, Mr. W. H. Herron, Mr. C. F. Urquhart, topographers, Mr. W. J. Lloyd and Mr. C. B. Green, assistant topographers, were assigned as his assistants. Several details were made from this section during the year. November 1, 1893, Mr. C. B. Green was transferred to the Southern California section. On April 20, 1894, Mr. W. H. Herron was detailed for service in the General Land Office, and on May 15 Mr. R. O. Gordon was detailed for service in the revision of the Pueblo atlas sheet, Colorado.

Washington.—Mr. R. H. McKee, topographer, was continued in charge of this section during the entire year.

Wyoming.—Mr. Frank Tweedy, topographer, was continued in charge of this section, assisted by Mr. C. C. Bassett, topographer. No change occurred in this section during the year.

Hydrographic.—This section was continued under charge of Mr. F. H. Newell during the entire year.

Parties were organized for the prosecution of field work in the various sections as the conditions of work demanded. It was usually necessary to subsist these parties in camps. The party organizations were nearly the same in the different localities and were constituted as described in my previous reports.

AREA SURVEYED.

All work was prosecuted in the different sections according to the general plan adopted by the U. S. Geological Survey, the methods of survey being the same as described in previous reports.

The following table shows the locality, by States, of areas surveyed, the scale of field work, the contour interval, and the number of square miles surveyed during the year:

Locality.	Scale of field work.	Contour interval.	Area surveyed.
		Feet.	*Sq. miles.*
California, Central	1: 95040	100	975
	1: 42240	25	50
California, Southern	1: 42240	25	600
Colorado	1: 63360	100	250
	1: 9600	15	15
Idaho	1: 95040	50	1,000
Oregon	1:253440	100	1,180
South Dakota	1: 95040	50	1,750
Texas	1: 95040	20	3,000
Washington	1: 95040	25	210
Wyoming	1: 95040	50	600
	1: 95040	100	2,000
Total			11,630

FIELD WORK OF SECTIONS.

California, Central.—The field work of this section consisted in the survey of the Yosemite atlas sheet, in the Gold Belt region, and in the continuation of the work about San Francisco Bay.

Three parties, one for triangulation and two for topographic work, were organized, under charge of Messrs. W. D. Johnson, R. B. Marshall, and S. P. Johnson, respectively. The party under Mr. W. D. Johnson extended its work to the east and north of the triangulation of the preceding year. To the topographic party under Mr. Marshall was assigned the mapping of the southern half of the Yosemite atlas sheet, and to that under Mr. S. P. Johnson the northern half. The parties commenced outfitting at Stockton, Cal., on July 1, and as soon as possible proceeded to the fields of their work.

The triangulation party worked with great energy until September 10, when Mr. Johnson was taken ill, in the almost inaccessible region about Mount Dana, and forced to abandon his work and disband his party. A sufficient number of stations, however, were located to furnish control for the season's work, and also for two sheets adjacent, designated as the Sonora Pass and Mount Lyell sheets. Upon Mr. Johnson's recovery I directed him to proceed to the field office at San Francisco and make the necessary arrangements for the office work of the parties. Having completed this duty, November 15 he was directed to proceed to Washington, D. C., for office work during the winter. The topographic party under Mr. Marshall finished mapping the area assigned it November 15. Mr. Marshall was then directed to run a level line from the office of the superintendent of the Yosemite National Park to the station of Raymond on the Southern Pacific Railroad. Owing to the late time of commencing this work great difficulty was experienced from storms and snow, and in spite of the energy and perseverance of Mr. Marshall and his party, he was forced to leave the field December 21, after running 33 miles. However, he succeeded in making connection with the level line run by the United States Central Railway Company, on the divide between Fresno and Chowchilla Creek, about 7 miles southwest of the post-office at Wawona. This connection gives a base of sufficient accuracy for the hypsometric work of the Yosemite and adjacent sheets and furnishes the most reliable data extant for the elevations of all points in that region. After the completion of his field work Mr. Marshall was directed to attend to the storage of all camp equipage and field material at Stockton, Cal., and to the placing of all animals used by the section during the season in winter quarters at Madera, Cal. Upon the completion of this duty he was directed to proceed to the field office of the Survey at San Francisco and prepare his season's work for the engraver. He completed this task April 10, and was then directed to commence field work on the Walnut Creek, San Bruno, and San Francisco atlas sheets, assigning the first sheet to Mr. W. H. Otis, and himself taking immediate charge of the others. This work is being vigorously prosecuted at the present time.

The topographic party under Mr. S. P. Johnson completed on October 15 the area assigned to it. Mr. Johnson was then directed to store his camp equipage and field material at Stockton, Cal., to place his animals in pasturage, and to proceed to the field office at San Francisco and prepare his work for the engraver. On February 1, 1894, and before completing his office work, Mr. Johnson resigned his position in the Survey. Mr. W. H. Otis, who had been Mr. Johnson's assistant, was then directed to complete the work. This Mr. Otis accomplished April 10, and then was directed to commence field work on the Walnut Creek sheet, as before stated.

California, Southern.—The field work of this section consisted of the survey of the whole of the West Los Angeles and Downey sheets and of part of the Calabasas, East Los Angeles, and Redondo sheets, all lying adjacent to one another.

Three parties, one for triangulation and two for topographic work, were organized, under charge of Mr. A. P. Davis, Mr. W. S. Post, and Mr. Paul Holman, respectively. These parties were outfitted at Los Angeles, and were in the field early in July. The party under Mr. Davis extended triangulation over the area designated to be mapped during the year, and also made connection with the triangulation near San Bernardino, Cal. Mr. Davis completed this task, in addition to the supervision of the topographic work of the other parties, November 1, 1893. He was then directed to proceed to Washington, D. C., for office work. That assigned him he completed May 1, 1894, and was then directed to resume charge of field work in his section, a duty upon which he is now engaged.

To the party under Mr. Post was assigned the survey of the West Los Angeles sheet and that portion of the Calabasas sheet included in the drainage basin of Santa Monica Creek. This work was commenced July 15, 1893, and completed December 10. Mr. Post was then directed to disband his party and to proceed with his assistants, Mr. Thomas S. Gerdine and Mr. C. B. Green, who had been detailed from the Texas section, to the field office at Los Angeles, Cal., and prepare his map for the engraver. He is at present engaged on this work.

To the party under Mr. Holman was assigned the survey of the Downey sheet. This work was commenced July 15, and by December 10 the southern half of the sheet was completed. Mr. Holman was then directed to disband his party and to proceed to the field office at Los Angeles and prepare his map for the engraver. On the completion of this work, May 15, Mr. Holman was directed to again take the field with a small party and complete the northern half of the sheet. He is at the present time engaged on this work.

In May, 1894, a small party under charge of Mr. Gerdine was organized for field work on the Redondo atlas sheet. Work was commenced May 22, and is being vigorously prosecuted at the present time.

On May 15, 1894, Mr. C. B. Green was detailed from this section and directed to proceed to Colorado for field work on the revision of the Pueblo atlas sheet.

Colorado-South Dakota.—The field work of this section consisted, in Colorado, of the survey of the Aspen atlas sheet, the completion of the survey of the Aspen mining district, the revision of portions of the Pueblo, Pikes Peak, and Platte Canyon sheets, and the commencement of the survey of the Cripple Creek mining district. In South Dakota, the work comprised the survey of two atlas sheets, known as the Hill City and the Oelrich sheets.

Five parties were organized for the work of this section: one triangulation party, under Mr. Douglas, for work in both States as required; two topographic parties in Colorado, under Mr. McKinney and Mr. Corse, respectively; and two in South Dakota, under Mr. R. A. Farmer and Mr. T. M. Bannon, respectively.

These parties were organized and took the field early in July. The triangulation party, under Mr. Douglas, first executed sufficient triangulation on the Aspen sheet and on the special maps of the Aspen mining district to control the topography of these areas. This work was completed August 7. Mr. Douglas then proceeded to South Dakota and extended the triangulation over the areas designated to be mapped, and also over two atlas-sheet areas to the westward. In addition to the triangulation, Mr. Douglas measured a base-line, 25,796.115 feet in length, near Rapid City, S. Dak. This line was measured three times with a 300-foot steel tape, which had been compared with the mural standard of the U. S. Coast and Geodetic Survey. When in use the tape was supported at intervals of 50 feet and placed under a uniform tension of 20 pounds. The probable error of the average of the three measurements is 0.084 of an inch.

The party under Mr. McKinney completed on October 15 the area assigned it. Mr. McKinney was then directed to report at Washington, D. C., for office work. The party under Mr. Corse completed the mapping of the Aspen mining district October 5. Mr. Corse was then directed to proceed to Pueblo, Colo., and begin revision of the Pueblo atlas sheet. He commenced this work, but on October 20 was forced to discontinue it on account of sickness. Mr. R. O. Gordon was then detailed from the Texas section to continue the work begun by Mr. Corse. Mr. Gordon continued the work until December 1, when he was forced by heavy snows and bad weather to suspend operations for the winter, and was directed to proceed to Washington, D. C., for office work.

May 10 Mr. Gordon was directed to resume field work on the Pueblo atlas sheet, where he is at present engaged. He is making good progress, although delayed by the severe storms and floods that have prevailed in the region.

May 9 Mr. Corse was directed to proceed to Colorado Springs, Colo., and organize a party for the survey of the Cripple Creek mining district, on a scale of $2\frac{1}{2}$ inches to the mile. Mr. George O. Glavis, assistant topographer, was assigned as Mr. Corse's assistant. Mr. Corse organized his party and reached Cripple Creek May 20, but was delayed in his work by the labor troubles prevailing in the district. Early in June, 1894, it was decided to increase the force engaged on the Cripple Creek survey, and Mr. E. M. Douglas, chief of the section, was directed to proceed to the field and organize such parties as were necessary for the rapid completion of the survey and to assume personal direction of the work. Mr. T. M. Bannon, assistant topographer, was detailed as an assistant. With this increased force the work is progressing rapidly.

The parties in South Dakota were organized and placed in the field July 10. To the party under Mr. R. A. Farmer was assigned the survey of the Harney Peak atlas sheet, and to the party under Mr. T. N. Bannon, the survey of the Oelrich sheet.

September 30 Mr. Farmer, after having completed the survey of 700 square miles of the Harney Peak sheet, was transferred to Colorado and directed to revise portions of the Pikes Peak and Platte Canyon atlas sheets. He completed the work assigned him November 15, and was then directed to proceed to Washington, D. C., for office work, upon which he has been engaged to the present time.

Mr. Bannon completed November 20 the Oelrich sheet and that portion of the Harney Peak sheet left undone by Mr. Farmer's transfer to Colorado. He was then directed to proceed to Washington, D. C., for office work. He remained on this duty until June 10, 1894, when he was assigned to field duty in the Cripple Creek mining district.

Idaho-Oregon.—The field work of this section in Idaho consisted of the survey of the northern half of the Garden City sheet, the extension of triangulation eastward from the present mapped area over two atlas-sheet areas, and the making of a map, on the scale of 4 miles to an inch, of the area included in this triangulation. The field work in Oregon included the completion of the survey of the Grants Pass sheet, some work in the vicinity of Portland, Oreg., the measurement of a base-line and the partial determination of the latitude and longitude of the observatory of the State University of Oregon, at Eugene, and the extension of a system of triangulation to connect this base-line and astronomical determination with the triangulation of the Grants Pass and Roseburg sheets. For the work of this section three parties were organized, one for triangulation and one for topographic work in Oregon, and one for both triangulation and topographic work in Idaho. Mr. W. T. Griswold, chief of the section, took immediate charge of the triangulation party in Oregon, and Mr. A. C. Barclay was given charge of the topographic party in Oregon and Mr. E. T. Perkins of the triangulation and topographic party in Idaho.

The parties in Oregon commenced work July 7. By September 1 the party under Mr. Griswold had completed the triangulation over the area assigned it. Mr. Griswold then proceeded to Portland, Oreg., and commenced work in the vicinity of that place on the scale of 1 mile to the inch. This work was prosecuted until stopped by rains December 1. The topographic party under Mr. Barclay was greatly delayed by rains, but finally succeeded in completing the Grants Pass sheet and a portion of the Roseburg sheet by November 10. Mr. Barclay was then directed to disband his party and proceed to the field office established at Portland, Oreg., for office work.

May 15, 1894, these parties again took the field, with instructions to measure a base-line, for topographic work, near Eugene, and extend the triangulation from this base-line to a connection with the stations on the Grants Pass and Roseburg sheets. The determination of the base-line was completed June 10. It was measured with a 300-foot steel tape, especially made for this purpose, its true length being determined by comparison with the mural standard of the U. S. Coast and Geodetic Survey. The line was measured twice, with a resulting average length, before corrections were applied, of 18,633.47 feet, the difference between the measurements being 1.68 feet. Upon completion of the measurement of the base-line, Mr. Griswold, assisted by Mr. Barclay, commenced triangulation. He was engaged on this work until June 25, when, leaving Mr. Barclay to continue the selection of stations and the erection of signals, he proceeded to Eugene to assist in the determination of the latitude and longitude of the observatory at that place.

Mr. S. S. Gannett, of the Eastern Division of Topography, was detailed to take charge of the latitude and longitude observations at

Eugene. For the determination of longitude, arrangements were made, by the courtesy of the U. S. Coast and Geodetic Surveys, to exchange time signals with the observatory at San Francisco, Prof. George Davidson having charge of the observations at that place. The Western Union Telegraph Company kindly placed a line at our disposal to effect these exchanges. Mr. Gannett left Washington, D. C., June 6, and proceeded to San Francisco to determine his relative personal equation in observing with Professor Davidson. After some delays from stormy weather the necessary observations for this purpose were made. Mr. Gannett then proceeded to Eugene, Oreg., where he is at present engaged in the prosecution of the work assigned him.

The party in Idaho, under Mr. Perkins, was organized and commenced work July 3. This party first completed the survey of the northern half of the Garden Valley sheet, and then commenced the extension of triangulation east and north of the present mapped area in Idaho. In connection with the triangulation, Mr. Perkins executed a topographic survey of the area covered by the triangulation, on a scale of 4 miles to an inch. This topographic work was done for the purpose of furnishing needed information regarding an almost unknown region, and not being on the scale used in the topographic work of Idaho, and not covering atlas-sheet areas, is not referred to in the table of areas surveyed. October 15 Mr. Perkins's party completed the area assigned, and as heavy snows had already fallen he was directed to disband his party and proceed to Washington, D. C., for office work. Mr. Perkins completed his office work May 1, 1894. He was then directed to proceed to Idaho, reorganize his party, and commence topographic work on the Weiser sheet. This work he is prosecuting at the present time.

Texas.—The field work of this section consisted of the survey of two atlas-sheet areas, designated as the Marfa and Alpine, in the trans-Pecos region of Texas, and of the Sherwood sheet, lying west of San Angelo.

Four parties, one triangulation and three topographic, were organized. Mr. R. U. Goode, chief of this section, in addition to his duties of inspection and supervision, assumed immediate charge of the triangulation party, and extended this work so as to furnish control points over the areas assigned for survey this season, and also over two additional atlas-sheet areas for future operations. In addition to triangulation, this party also ran a sufficient number of level lines to control the elevations of this season's work. November 15 Mr. Goode completed the duties assigned to him, and proceeded to Washington, D. C., for office work.

To the topographic party under Mr. Gordon was assigned the survey of the Marfa sheet. He completed this October 20, and was then detailed to work in Colorado, as stated in the report of that section.

To the topographic party under Mr. Urquhart, assisted by Mr. Green, was assigned the survey of the Alpine atlas sheet. This work was completed November 1. Mr. Urquhart was then directed to proceed to Washington, D. C., for office work, and Mr. Green was directed to proceed to Colorado to assist Mr. Gordon in the revision of the Pueblo atlas sheet.

To the topographic party under Mr. Herron, assisted by Mr. Lloyd, was assigned the survey of the Sherwood atlas sheet. This work was completed November 10, when Mr. Herron and Mr. Lloyd were directed to proceed to Washington, D. C., for office work.

Washington.—The field work of this section consisted in the survey of the Seattle and part of the Gilman atlas sheets. One control and topographic party, under Mr. R. H. McKee, was organized for this work. This party commenced work early in July and continued until November 10, when further field work was discontinued on account of excessively rainy weather. Mr. McKee was then directed to proceed to the field office at Seattle and prepare his work for the engraver. Having completed his office work, May 15, 1894, Mr. McKee was directed to resume field work on the Gilman sheet. This duty he is engaged on at the present time.

Wyoming.—The field work of this section consisted of the survey of two atlas-sheet areas lying directly east of the Yellowstone National Park, the completion of the Dayton sheet in the same region, and the completion of the Laramie and part of the Medicine Bow sheets in southern Wyoming.

Two parties were organized for this work, under charge of Mr. Frank Tweedy, chief of the section, and Mr. Bassett, his assistant, respectively.

To the party under Mr. Tweedy was assigned the area east of the Yellowstone National Park. This party was somewhat delayed in commencing work by reason of the accidental death of its chief packer, Mr. Amos Scott, a man who had been in the employ of the Geological Survey for more than ten years and whose faithful services had endeared him to all those under whom he had served.

July 11 the party began work on the unfinished part of the Dayton sheet. Completing this sheet, work was prosecuted on the area east of the Yellowstone National Park until October 20, when, the assigned territory being surveyed, Mr. Tweedy disbanded his party at Red Lodge, Mont., and proceeded to Washington, D. C., for office work.

To the party under Mr. Bassett was assigned the survey of the uncompleted portion of the Laramie and the eastern half of the Medicine Bow atlas sheets. The work was commenced July 1 and prosecuted energetically until November 10, when Mr. Bassett was directed to disband his party and proceed to Washington, D. C., for office work.

Hydrography.—The work of this section consisted of the gaging of streams west of the one hundreth meridian, and will be reported on in detail by Mr. F. H. Newell, who is in immediate charge of this work.

OFFICE WORK.

Immediately upon the close of the field season in each section the chiefs of parties, with their permanent assistants, were directed to proceed with the preparation of the final maps of their surveys, for the engraver. The members of the central section of California proceeded to the field office in the U. S. Appraiser's building at San Francisco for this work; the members of the California southern section, to a field office at Los Angeles; the members of the Oregon-Idaho section, to Portland, Oreg.; and the members of the Washington section, to Seattle, Wash. The members of the other sections reported at Washington, D. C.

All office work has been completed up to date. In addition to the preparation of the field work of this division for the engraver a large amount of office work has been done in compiling and placing on maps various data for use in the general office and field.

Details have also been made from time to time of men to assist in the work of the General Land Office, by examining plats, contracts, etc., of deputy surveyors.

The following table shows the locality of each atlas sheet prepared for the engraver, the name of sheet, contour interval, scale of field-work, and scale of publication:

State.	Name of sheet.	Contour interval.	Scale of drawing.	Scale of publication.
		Feet.		
California	Yosemite	100	1 inch = 1½ miles	1:125000
	West Los Angeles	25	1½ inches = 1 mile	1: 62500
Colorado	Aspen	100	1½ inches = 1 mile	1: 62500
	Tourtelotte Park (special)	25	1 inch = 800 feet	
	Richmond Hill (special)	25	1 inch = 800 feet	
	Hunter Park (special)	25	1 inch = 800 feet	
	Lenado (special)	25	1 inch = 800 feet	
Idaho	Garden Valley	100	1 inch = 1½ miles	1;125000
Oregon	Grants Pass	200	1 inch = 2 miles	1:250000
South Dakota	Harney Peak	100	1 inch = 1½ miles	1:125000
	Oelrich	50	1 inch = 1½ miles	1:125000
Texas	Sherwood	20	1 inch = 1½ miles	1:125000
	Marfa	20	1 inch = 1½ miles	1:125000
	Alpine	20	1 inch = 1½ miles	1:125000
Washington	Seattle	25	1½ inches = 1 mile	1: 62500
Wyoming	Laramie	250	1 inch = 1½ miles	1:125000
	Dayton	100	1 inch = 1½ miles	1:125000
	Crandall Creek	100	1 inch = 1½ miles	1:125000
	Ishawooa	100	1 inch = 1½ miles	1:125000

DISBURSEMENTS OF MONEY.

The disbursement of money for this division has been under charge of Mr. James W. Spencer, the duties being performed from the general office at Washington, D. C., and from a field office established during the field season at Colorado Springs, Colo.

SUPERVISION OF WORK.

In pursuance of your orders continuing me in charge of the Western Division of Topography, I left Washington, D. C., July 17, 1893. From that time until December I was engaged in visiting parties in the field, consulting with chiefs of sections, inspecting property, and examining and planning work and giving general directions for its execution. These visits were made as the exigencies of the work demanded. Some parties were visited twice, others only once. In the case of the Texas section, I was not able, from lack of time, to visit the parties during the season. In the prosecution of my work I made three trips to Colorado Springs, Colo., to inspect and certify to the accounts of the disbursing agent and sign requisitions for funds.

As custodian in charge of property, I examined, as often as practicable, all the instruments, camp equipage, and field material, made reports as to its amount and condition, and, when necessary, recommendations in regard to the same.

I returned to Washington, D. C., December 10, and assumed general charge of the office work, directing that of the field offices by letter.

I am, very respectfully, your obedient servant,

A. H. THOMPSON,
Geographer in Charge, Western Division of Topography.

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

REPORT OF MR. C. D. WALCOTT.

U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGY AND PALEONTOLOGY,
Washington, D.C., June 30, 1894.

SIR: I have the honor to submit the following report of the work of the Division of Geology and Paleontology for the fiscal year ending to-day.

During the previous year the members of the organization that existed prior to July 1, 1892, were engaged in placing on record, in manuscript and on maps, all their field observations. At the opening of the present fiscal year a reorganization was made of the geologic branch by disbanding all the old divisions and organizing twenty-three field parties, the geologist placed in charge of each receiving instructions to make areal surveys in certain areas. A summary of this work is here given, and more detailed accounts may be found in the reports of the several chiefs of parties to the Director, appended hereto.

WORK OF GEOLOGIC PARTIES.

Southern Appalachian region.—The work in this region was assigned to Messrs. C. W. Hayes, Arthur Keith, and M. R. Campbell. They were instructed to finish the atlas sheets left incomplete by reason of the reduction of appropriations in the summer of 1891-92, and then to survey certain sheets before the close of the field season.

Mr. Hayes first took up the incomplete Rome, Ga., and Fort Payne, Ala., sheets, surveying 190 square miles in the former and 200 square miles in the latter. He also did certain revision work on the Dalton, Ga. (120 square miles), and the Anniston and Stevenson, Ala., sheets (80 square miles), in order to bring them to date. He then made a detailed survey of the Sewanee, Tenn., sheet (975 square miles). The last named embraces a considerable area of the productive coal measures of the State of Tennessee. In connection with this work, a reconnaissance was made of 80 square miles in the adjoining Pikesville sheet. The revisional work was in the main in regions of highly complicated structural geology.

In the Rome and Fort Payne areas special attention was given to the deposits of iron and aluminum ores, and their intimate relations to the structure of the region were carefully studied. In the Sewanee area attention was given largely to a thorough examination of the coals. Practically all exposures, natural and artificial, of which knowledge could be obtained, were visited, and many sections of the coal measures procured. This will form the basis for a fairly complete map of all the workable coal beds in the region. Important scientific results were obtained that will be of special service in the further development of the geology of the region.

In the office Mr. Hayes was employed in preparing the maps of the Sewanee, Tenn., folio, and accompanying text. Completing this, he revised the maps and text of the Rome, Fort Payne, and Dalton sheets, in addition to preparing a descriptive paper upon the deposits of bauxite in Georgia.

Mr. Arthur Keith completed the partially surveyed sheets of Cranberry and Nantahalah, N. C., and Murphy and Mount Guyot, Tenn. and N. C., which involved the surveying of 575 square miles of area. He also surveyed the Roan Mountain sheet, in Tennessee and North Carolina, which includes 900 square miles of area, and the Briceville, Tenn., sheet, about 985 square miles, two-thirds of which is within the productive coal field of Tennessee.

Large numbers of magnetite, brown hematite, and corundum deposits were examined on the Roan Mountain sheet, and the coal deposits of the Briceville sheet were worked up in detail. The scientific results of the work are valuable and will be of service in the development of the resources of coal and iron within the region surveyed.

After returning from the field Mr. Keith was employed in the compilation of notes, drafting of maps, etc., and in the preparation of manuscript to accompany the atlas sheets and special reports. This included the descriptive text to accompany the Harpers Ferry, Knoxville, Greenville, and Loudon folios.

Mr. Campbell's work included a complete survey of the Pocahontas, Va., sheet (950 square miles) and the Bristol, Tenn., sheet (800 square miles), and also the survey of the Dublin, Va., sheet (950 square miles), which was completed with the exception of about ten days' work. In addition 200 square miles were surveyed on the Wytheville, Abingdon, and Hillsville, Va., sheets, along the boundary lines of the sheets above mentioned, as it was necessary at times to carry the survey into adjoining sheets in order to fully work out the problems.

Parts of the Pocahontas and Bristol sheets are in important coal territory, the deposits of which are destined to become very valuable when developed. Other parts of the territory are rich in iron ores that at present are undeveloped. The work lay in a region containing the connecting links between the northern and southern phases of many geologic formations. Valuable data were also obtained concerning the post-Paleozoic history of this portion of the Appalachians. Mr. Campbell prepared for publication the geologic boundaries, structure and columnar sections, and text of the Pocahontas sheet, and the text of the Estillville sheet; also several papers upon various geologic phenomena in the district he has surveyed.

New York and northern Appalachian region.—Mr. N. H. Darton was detailed to work in cooperation with the State geologist of New York, for the purpose of obtaining geologic data to give greater accuracy to the geologic map that is about to be published. He reports that he has completed 2,300 square miles in the Mohawk Valley, the Helderberg Mountains, and the region east of the Hudson River Valley, and made a reconnaissance of an area of 960 square miles. The economic results are the ascertainment of the distribution of the several lime stone belts and the determination of the limits of the Rosendale–Rondout cement region and of the flagstone belt. The scientific results are the elucidation of the nature of the faults of the Mohawk–Adirondack region and of the structure of the folded region from Albany County to Orange County. The descriptive texts for several of the atlas folios were prepared, and reports were made on the geology of Albany and Ulster counties and on the faulted region of Fulton, Montgomery, Saratoga, Herkimer, and adjacent counties.

Mr. T. Nelson Dale was engaged in mapping the areal geology of the Troy, N. Y., atlas sheet. This sheet completes one of the great sections from the Connecticut to the Hudson River, and it also embraces the southward extension of the formations in which the roofing-slate belts of Washington County occur. It is proposed to continue areal mapping to the north as fast as the topographic maps are prepared, so as to entirely cover the roofing-slate belt of New York and Vermont. In the office Mr. Dale was engaged in the preparation of the text for the Troy atlas sheet.

Dr. George H. Williams, of Johns Hopkins University, Baltimore, was engaged in the areal mapping of the crystalline rocks of the West Washington, Frederick, and Gunpowder atlas sheets of Maryland.

The time and means at Dr. Williams's disposal were limited, but the West Washington sheet was completed and considerable work was done on the other sheets mentioned. Laboratory and office work was confined to the study of material collected in the field and the preparation of reports upon various investigations, which will be submitted in the future.

Atlantic Coast region.—Dr. W. B. Clark, of Johns Hopkins University, Baltimore, was engaged in the main in mapping the Cassville, N. J., sheet, which he practically completed. This sheet has an area of 235 square miles. By reason of the extensive covering of later deposits the mapping of the Cretaceous and Tertiary formations was advanced more slowly than in the area to the northward. In order to ascertain the relationship of the several formations it was deemed necessary to work out in detail several type sections across the State, and these, by the aid of borings made at frequent intervals, gave excellent results. A short time was given at the beginning of the field season to the completion of the previously surveyed New Brunswick and Sandy Hook sheets, a small amount of work on which remained to be done. In the office Dr. Clark studied the data obtained by him in relation to the New Brunswick and Sandy Hook sheets and prepared the texts for the same.

Field work was carried forward by Dr. J. E. Wolff, of Harvard University, in the Archean highlands of New Jersey, during July, August, and September, within the area of the Lake Hopatcong sheet. The survey of about 100 square miles of the sheet was practically completed. Great care was taken in indicating upon the map all phenomena that could be of service in the development of the iron mines of the district. Attention was also given to the occurrence of masses of rock of exceptional value for road material and building-stones. During the winter a paper was prepared on the geologic structure of the region in the vicinity of the Hibernia ore deposits. Dr. Wolff came to the conclusion that this ore bed is one of the largest in New Jersey and that it should be looked for far beyond its present northernmost workings.

Mr. J. Stanley-Brown was placed in charge of work on the Coastal Plain formations and instructed to make himself familiar with the various formations, preliminary to taking up areal work. In association with Dr. W. H. Dall, he examined during the season about 200 square miles of area in southern Georgia and northern Florida, for the purpose of establishing a geologic column which would be a key to the geologic formations of that region. He also made short trips in the vicinity of Washington, D. C., to typical localities in the Coastal Plain formation, and examined critically an area of from 40 to 50 square miles on the Gunpowder sheet of Maryland. At the close of May Mr. Stanley-Brown resigned his position in the Survey to take charge of work in connection with the Alaskan seal industry.

During the period embracing the months of March to June, inclusive, Mr. George H. Eldridge resumed and continued his work in the phosphate fields of Florida, delineating in detail the phosphate-bearing formations and examining the extent and value of the deposits. Considerable time was given to the study of methods of mining and of the preparation of phosphate rock for the market. A reconnaissance was made also in southern Georgia for phosphate deposits of economic value. The work in the northern portion of Florida is nearly complete; in southern Florida it is well advanced, but in less areal detail than in northern Florida.

Further reference to Mr. Eldridge's work is made in connection with the account of a geologic reconnaissance in the Rocky Mountain region.

The work in charge of Prof. N. S. Shaler related almost entirely to the advance of the areal survey of the surface geology of the New England States. Professor Shaler was assisted by Mr. J. B. Woodworth, who was engaged in field work in the region about Narragansett Bay and in revising the work of assistants in certain parts of Connecticut and Massachusetts. Mr. R. E. Dodge did field work on several sheets in Connecticut. Mr. L. H. Davis prepared the maps and reports of the Bridgeport and Norwalk sheets (Connecticut) and also certain portions of the Pittsburg and Berlin sheets, which lie in the State of New York, and Mr. G. H. Barton was engaged in completing the delineation of the drumlins in Massachusetts and in southern Vermont and New Hampshire. In the office Professor Shaler prepared a "Preliminary Report on the Geology of Common Roads," and information was obtained and given to inquirers relating to water supply, drainage, peat deposits, and the use of gravels for filtration; to the sources of supply for railroad ballast, materials for roadmaking, and pottery clays. Ten atlas sheets, with accompanying texts, were forwarded to Washington for publication.

Lake Superior region.—The work in the Lake Superior region, under charge of Prof. C. R. Van Hise, included the areal mapping of the country adjacent to the Marquette iron-bearing district of Michigan. The area covered was 275 square miles, which completes the unsurveyed part of the district and joins the areas previously surveyed on the north and south. This area is not large, but a good deal of it was a complicated part of the Marquette district; and this district is the key area of the Lake Superior region. The broad expanses of rocks with more simple geology north, south, and west of this district, were surveyed at a much greater speed, and maps of large areas will be prepared for publication as soon as the topographic base is made.

The chief economic result reached in the Lake Superior region this year is a demonstration that the various ores and ferruginous schists of the Marquette district are derived from an original lean carbonate of iron. This fact had already been demonstrated for the Penokee and Animikie districts, but had not been shown to be the case for the Lower Huronian rocks. Professor Van Hise also worked out stratigraphic and structural details that will be of service in the development of the iron ores of the region. In the office the entire time of Professor Van Hise and his assistants, Messrs. W. S. Bayley and H. L. Smyth, was given to the preparation of a preliminary report on the Marquette iron district.

Rocky Mountain region.—The work in Montana was in charge of Mr. W. H. Weed, who surveyed 1,785 square miles, embracing the northern portion of the Little Belt Mountain sheet. Within this area are several important mining districts, and in these the work was done in more detail than in the other parts of the area. Sixteen different sedimentary deposits and eleven different formations of volcanic rocks were determined and mapped. The mineral deposits of the region are all connected with the volcanic rocks, and much more time was given to their study than to that of the sedimentary formations.

The economic work included an examination of the Sixteen Mile copper district, the Castle mining district, Copperopolis, Sheep Creek, Toga, and Neihart mining districts. No attempt at a detailed study of the mining camps was attempted, the time available for the observations being only sufficient to ascertain the geologic relations of the ore beds and to determine the probable productive areas and the general character of the ores. A large number of prospects and such mines as were working or accessible were examined, and it is believed that the results will be of direct value to the mining community of the region as well as of general scientific interest. Among the scientific results obtained was the determination and study of two dissected volcanoes and the determination of a great series of sedimentary rocks beneath the oldest fossiliferous sediments.

A reconnaissance was made by Mr. Weed of the Deep Creek region of the Belt Mountains and the volcanic center that forms the nucleus of the range; also of the coal lands of the Judith country adjacent to the Big Snowy and the Moccasin mountains of the Judith basin. A brief examination was made of the region adjacent to Sixteen Mile Creek, in the Fort Logan sheet. The area covered by this reconnaissance aggregates 500 square miles. In the office Mr. Weed was engaged in writing up the report on the Castle mining district, in looking after the publication of the Livingston atlas folio, and in the preparation and study of data relating to the survey of the Yellowstone Park, in which work he was engaged for a number of years as assistant to Mr. Hague.

Mr. Arnold Hague continued his work in the Yellowstone Park area and also extended it into the forest area east of the park. In the latter region he began the study of the north end of the Absaroka Range in its relations to the older ranges to the westward, and in this connection a general examination of the mineral developments at Cook City was made, together with a study of the geographic position of this mining district with reference to the development of trade routes through the mountains. He completed the survey of the northernmost atlas sheet east of the park in August, and found that the geologic history of the region comprising the park begins with the history of the Absaroka Range. The survey of the atlas sheet south of the preceding was completed, and, with it, the study of the southern half of the Absaroka Range, to the high plateau which unites that range with the Wind River Range. One of the objects of Mr. Hague's work is the determination of the most practicable boundary for the eastern side of the Yellowstone Park and the determination of the presence or absence of valuable minerals within that boundary. He also obtained data within the present boundaries of the park that will enable him to proceed rapidly with the preparation of his report on the geology of that national reservation. On returning from the field Mr. Hague gave considerable time to the writing out of his field notes, and he then took up, during the winter and spring, the preparation of the maps and text for the folio atlas of the Yellowstone Park and the final monograph upon the geology of that region.

A reconnaissance of the Big Horn basin of Wyoming was made by Mr. G. H. Eldridge, for the purpose of determining the extent of workable coals. The area embraced about 2,500 square miles, extending from the prairies east of the Big Horn Range into the Absaroka and Shoshone mountains on the west, and from a line about 15 miles north of the Montana–Wyoming boundary line to the Wind River Mountains on the south. The economic results of this reconnaissance will be a report upon the coal, oil, and building stones, the possibility of artesian flow, and the area available for agriculture. The coal was found to be generally a lignite, bordering, in the Wood River region, on the lowest grade of bituminous, but yet a coal which is somewhat similar to the Rocky Fork coal of Montana, mined for locomotive use. The areas of this coal will be given, although they have not been fully worked out in detail. The building stones are varied in color and quality, and many suitable for various architectural purposes were observed. There are many opportunities for securing artesian water flow throughout the basins of the region, and the areas available for agriculture are found chiefly along stream bottoms and in the valleys adjacent to the streams. The scientific results include the construction of a map of the region on the Land Office base, showing the distribution of formations and the geologic structure, and a vertical section illustrating the stratigraphy.

In the office Mr. Eldridge was employed from October to February in preparing a report on his reconnaissance in Wyoming. This report was submitted for publication and is now in press.

Mr. Whitman Cross was instructed to map the areal geology of the Pikes Peak sheet, with special reference to the distribution of the metalliferous rocks, in connection with the Cripple Creek mining district. This mining region has been discovered and geologically exploited within a relatively short period. It is in the center of the district and has peculiarities of geology and ore deposition that are very imperfectly understood. Mr. Cross mapped the entire sheet of 930 square miles, determining the characters of the various volcanic rocks in which the ore deposits occur, and also the extent and distribution of those deposits and of the sedimentary formations included within the area.

The study of the district has led to a clear understanding of the geology about Cripple Creek, and shows that the gold ores occur in igneous rocks of a local volcanic vent or in the granite immediately adjacent. This has made it clear that the deposits must be studied and worked from the basis of a knowledge of volcanic geology if the best results are to be obtained. The survey has accurately limited the district within which workable deposits may reasonably be expected, and has indicated the criteria to be kept in view in prospecting a large area to the westward of the Pikes Peak sheet. Further mention of the economic results will be made after the completion of a study of the ore deposits that is now under way.

The scientific results of Mr. Cross's work are of an interesting character. He found six or eight distinct kinds of granite in the area, and discovered that both gneisses and schists are produced from these granites by dynamic metamorphism. He has shown that these granites are full of inclusions of pre-Cambrian quartzites, which proves to his view that the granites which have heretofore been classed as Archean are of much later date, and are either Algonkian or post-Algonkian in age. The interbedded Algonkian rocks occur as inclusions in the granite, some masses of which are several miles in length, and one is 3,000 feet or more in thickness. These illustrations give some idea of the force of the repeated granitic eruptions. The work upon the sedimentary rocks included the determination of the various formations and the mapping of their distribution. The working-out of the unconformities, faults, and folds will have an important bearing on the structural history of the Front Range of the Rocky Mountains. In the volcanic formations numerous discoveries were made that will be of great interest to the student.

In the office Mr. Cross was employed almost exclusively in work pertaining to the geology of the region studied during the season. This included the study of the rocks and minerals and the preparation of the geologic map and the descriptive text of the Pikes Peak folio. Attention was also given to the revision and proof reading of the geologic maps of the Crested Butte and Anthracite folios.

The mapping of the areal geology of the Pueblo sheet was assigned to Mr. G. K. Gilbert. His work included an area of 941 square miles, and the field work was completed at the close of the season. The principal economic result is a determination of the local conditions affecting the supply of artesian water. The Dakota sandstone, underlying the greater portion of the area, is a water-bearing stratum, and the structural and areal data make it possible to prepare a map showing the depth below the surface at which the water-bearing stratum can be found at any locality. Indications can also be made of the districts at which it may be expected that water will rise to the surface if reached by boring. These data will be compiled when the revision of the topographic map shall have been completed.

The chief scientific result is a contribution to the stratigraphy of the Cretaceous formations. The position of a shore-line of Eo-Juratrias date along the Rocky Mountains was determined. A large collection of fossils was secured for the purpose of discriminating the horizons in the Cretaceous.

Considerable progress was made upon the Cottonwood Falls, Kans., sheet, by Prof. C. S. Prosser, who worked under Mr. Gilbert's general direction. The succession of rocks was determined and certain boundaries were traced across the sheet. The areal work may be reported as in a condition of reconnaissance, more than half of the field work having been completed.

In the office Mr. Gilbert was engaged in the study of the material collected during the field season and in writing out his field notes. He also gave some time to the development of plans for the mechanical solution of the problem of least squares.

Prof. R. T. Hill assisted Mr. Gilbert in the survey of the Pueblo sheet during the earlier part of the field season, and then returned to Washington, where he prepared for publication the results of earlier work. These results pertain to the general distribution of formations in a large district adjoining the medial portion of the Red River, to the stratigraphy of the earlier Cretaceous in Texas, to the relations between the formations of the Llano Estacado and those of the Gulf Coast, and to the areal geology of the Fort Worth, Weatherford, Dallas, and Temple sheets of Texas. The geology of the last-mentioned district was discussed with special reference to artesian-water conditions.

Pacific Coast region.—In northern California Mr. J. S. Diller carefully surveyed 880 square miles and made a searching reconnaissance of 2,790 square miles. This included the completion of the Lassen Peak sheet and work upon the Honey Lake, Red Bluff, Mount Shasta, and Modoc sheets, all of which border on the Lassen Peak sheet.

The economic results secured refer especially to the completed areas. It was discovered that all the mines of the Greenville region are essentially on contacts bordering masses of ancient eruptive rocks, such as serpentine, granite, and diorite. A knowledge of this fact and the publication of maps showing the geographic distribution of these contacts will give to prospectors a valuable and much-needed guide in their search, and to mine operators an important suggestion concerning the direction of development. The mapping of the limits of auriferous gravels will indicate the possibilities for hydraulic mining. The scientific results are drawn largely from the reconnaissance work.

Over two tons of fossils were collected, chiefly from the Cretaceous, though a small proportion were obtained from the Carboniferous, the Juratrias, and the Miocene. By the aid of these fossils important correlations will be made and the various formations within the area can be surveyed. These paleontologic results were secured largely through the able field assistance of Mr. T. W. Stanton. An important deduction from the general study of the region is that, since the early Auriferous gravel period, there has been a great revolution in the topography of the Pacific Coast.

After returning from the field Mr. Diller revised and extended his paper on the revolution in the topography of the Pacific Coast since the Auriferous gravel period, and prepared for final publication the maps and text for the Lassen Peak folio. Mr. Diller has charge of the petrographic laboratory and did considerable work in the identification of material. He also continued the preparation of the Educational Series of Rocks and of the bulletin to accompany it.

To the south of Mr. Diller's field of work Mr. Waldemar Lindgren was engaged in the geologic mapping of the Truckee sheet, surveying in all 400 square miles on the scale of 2 miles to the inch. After the completion of the Truckee sheet Mr. Lindgren was occupied in plotting the geology of the large-scale, detailed maps of the Nevada City and Grass Valley mining districts. Of these the mapping of the Banner Hill sheet and of half of the Nevada City sheet was completed by December 1, 18 square miles being surveyed on a scale of 1,250 feet to the inch. All of the mines contained in the area were examined with care, but the work has not progressed far enough to permit any final conclusions and generalizations to be made. It is hoped to fix the location of old Tertiary river channels in the district and also to separate the different vein systems and make a detailed study of the ores and country rock, which may shed some light on the origin of the fissure systems and the process of vein formation.

The data obtained in the work on the Truckee sheet have important bearing on the structure of the Sierra Nevada in that latitude.

An important scientific contribution was obtained in connection with the history of Lake Tahoe. This shows that the lake has been dammed twice—first, by the flow of andesite lava, and latterly by the basaltic lavas—and that it is quite possible that it originally drained into the Sacramento Valley. The lake in Tertiary and Pleistocene time was very much more extended, and for this ancient lake Mr. Lindgren has proposed the name "Truckee." The shore deposits and glacial phenomena of this lake and basin were studied with care and with interesting results.

With a slight exception, Mr. Lindgren was employed during the entire year in field work.

Mr. H. W. Turner's work in the same region was confined to the Downieville and Bidwell Bar sheets. About 330 square miles were mapped in detail, the Downieville sheet being practically completed. This region is one of great complexity, there being a great variety of old igneous rocks mingled with the older sedimentary terranes, the whole having been subjected to great compression, resulting in the metamorphism of both igneous and sedimentary rocks.

Several large beds of magnetic iron ore were located on the Downieville sheet, as well as numerous gold-quartz veins; and all of the exposed areas of the Auriferous gravel series were mapped. The mapping of the distribution of the auriferous gravels in the Sierra Nevada will be particularly appreciated by the mining community, in view of the revival of the gravel method of mining. Important scientific results were obtained by the study of the relations of the igneous and sedimentary rocks, and these will be supplemented by microscopic study of the specimens collected. It was found that nearly all the Auriferous slates of the northern portion of the Downieville sheet were apparently of Paleozoic age.

Dr. A. C. Lawson was engaged, during the vacation period of the University of California and at various irregular intervals throughout the year, in the study of portions of the counties of San Francisco, San Mateo, Marin, Alameda, and Contra Costa, Cal. He was assisted by two graduate students of the university, with the result that the field work on the Montara, San Mateo, and San Bruno atlas sheets was completed. That portion of the field included within the San Francisco peninsula north of latitude 37° 30′ was sufficiently studied to permit of the discussion of its geology, and a paper was prepared for the annual report of the Director. Special studies were made in relation to various volcanic rocks, and short papers published upon them. These are necessary adjuncts to the more general work of the Survey. As the region adjacent to the Bay of San Francisco appears to be representative of a large part of the coast ranges of California, these special studies will, it is hoped, yield in the near future material for a monograph on a typical section of the coast ranges.

The original plan included surveys also in the basin of Puget Sound, Wash., Mr. Bailey Willis being assigned to that field. Mr. Willis was also charged with the editing of the folios of the Geologic Atlas of the United States, and this duty was peculiarly onerous by reason of the large number of questions to be settled in connection with the initial folios. It proved to be unadvisable for him to leave the office for any considerable period, and the contemplated field work was deferred.

Mr. Willis also gave much thought to the processes of sedimentary deposition, and to the relations existing between the phases of destructive erosion of the land and the nature of sediments resulting in the seas. The results have led to a logical conception of the physical geography of the Appalachian province during the Paleozoic era.

Superficial formations.—In addition to the study of the superficial formations under the direction of Professor Shaler, work was carried forward under the direction of Prof. T. C. Chamberlin, of the University of Chicago, who was given a small allotment for the purpose. An area of about 4,500 square miles was covered in southwestern New York by Mr. Frank Leverett. It is situated between the Genesee Canal on the east, the Erie Canal on the north, and Lake Chautauqua and its outlet on the west. Another line of investigation was a study of the ancient drainage system of the Ohio basin, embracing about 700 square miles. The work in both cases falls under the class of detailed or final work.

The principal scientific results obtained in New York are the mapping and correlation of the glacial moraines, the determination of the amount of lobation of the ice in certain deep valleys, and the interpretation of a peculiar form of moraine developed in the valleys.

The economic bearing of these investigations lies in the groundwork which they furnish for the classification of soils and the interpretation of the results of experience and experiment in agriculture, by supplying data concerning the origin and constitution of the subsoil from which the surface soils are derived. They also furnish a rational interpretation of the origin and nature of the topography of the region, and thus make a valuable contribution to the means of instruction in geography and physiography in the schools of the region.

A review was made by Professor Chamberlin and Mr. I. M. Buell of the distribution of the drift from the crystalline areas of south-central Wisconsin. This work was of the nature of a supplementary examination of critical points preparatory to the final revision of a report upon an area of about 6,000 square miles.

The office work consisted in preparing for publication the results of the field studies.

Cooperation in New York.—In cooperation with the State geological survey of New York, field work was carried on in the Mohawk Valley in the counties of Albany and Ulster. The expense of this work was shared by the State survey and the National survey, and it was executed by Mr. N. H. Darton. It consisted of reconnaissance and detail mapping. The detailed mapping will be used in the preparation of the geologic folios of the National survey and also in the preparation of the geologic map of New York by the State geologist. A report of this work was completed and transmitted to the State geologist.

Cooperation in New Jersey.—Prior to the reduction of appropriations in 1892, work was carried on by cooperation between the State survey and the National survey in the Archean region of the northern portion of the State and in the superficial formations of various portions of the State. This cooperative work was resumed by having Dr. J. E. Wolff make a detailed survey of a portion of the Lake Hopatcong sheet and Prof. W. B. Clark a survey of the Cassville sheet and of the uncompleted parts of the previously surveyed New Brunswick and Sandy Hook sheets. This work will result, as in New York, in the production of maps for the U. S. Geological Survey and in the development of the areal geology for the use of the State geologist in preparing the State map.

Cooperation in Georgia.—Cooperation with the State geologist of Georgia was entered into for the purpose of making an examination of the reported phosphate deposits of the southern part of the State. In March this work was placed in charge of Mr. George H. Eldridge, who made a reconnaissance, with the aid of an assistant of the State survey, whom he subsequently left to continue the work.

Paleontologic work.—Two of the paleontologists were assigned to field work in connection with geologic parties. Mr. David White assisted Mr. M. R. Campbell in his work on the areal geology of the Coal Measures of Virginia and West Virginia, and also assisted Mr. Arthur Keith during the last three weeks of October, in Tennessee. Mr. White's work was the determination by paleontologic evidence of the equivalency of the several coal beds in the region surveyed, and a study of the fossil plants collected for that purpose was made during the winter. In the spring Mr. White made a short trip in central Pennsylvania for the purpose of obtaining data by which to correlate the coal-bearing formations of Pennsylvania with those of West Virginia and Tennessee.

In the office he was employed in the study of field notes and collections and in the preparation of preliminary reports. Considerable time was given to the arrangement of the great Lacoe collection of fossil plants from the Carboniferous rocks of North America.

Mr. T. W. Stanton was attached to the parties of Messrs. Diller and Turner in the northern half of California. The paleontologic material collected by him furnished data for determining the age of several local formations—knowledge that was of immediate use to the geologists in their areal mapping. Mr. Stanton also made large collections of fossils in the Sacramento Valley, in connection with the study of the sections of Cretaceous rocks. These will furnish the basis for a more rational classification of the Cretaceous strata of the Pacific Coast than has prevailed heretofore. Collections were also made from the Juratrias rocks of the same region that will be of importance in classifying the formations of these systems.

Mr. Stanton's time in the office was given to the study of field notes and collections and to the identification of fossils sent to him by geologists of the Survey. He also assisted in the installation of the Geological Survey's exhibit at the World's Columbian Exposition.

Some doubt having been thrown upon the accuracy of the standard section of Florida and adjacent States adopted by the Geological Survey, Dr. W. H. Dall, accompanied by Mr. J. Stanley-Brown, made a trip South for the purpose of making a careful instrumental survey of the section between Bainbridge, Ga., and the marshes of the Gulf Coast. A reconnaissance survey was also made of Alum Bluff, an important locality, and of various localities on the Chipola River, where sections were carefully measured. The result of this work is to clear up the discrepancies of previous reports, correct the errors of estimation (so far as the measurements of sections are concerned), and give a firm basis of fact for future work.

In the office Dr. Dall has attended to the routine work upon the collections, and made several reports to geologists on material sent in for identification. He also continued work upon the final report on the Tertiary fossils of Florida.

Field work in vertebrate paleontology was abandoned two years ago, and the entire time of Prof. O. C. Marsh has since been devoted to the preparation of monographs upon the immense collections accumulated from 1882 to 1891, inclusive. He hopes to submit for publication during the next fiscal year a monograph on the Sauropoda. For this work 90 lithographic plates and 211 woodcuts are complete, and he is now at work on the text.

Professor Marsh has given considerable time to the work of determining definite geologic horizons by the aid of vertebrate fossils. Reports of two separate investigations on this line have been prepared and published within the last six months, both referring to the correlation of Tertiary rocks.

The work in paleobotany, under the charge of Prof. Lester F. Ward, was largely confined to office studies, with the exception of work on the Potomac formation in the District of Columbia, Maryland, and Virginia north of the Rappahannock. In this latter work he was assisted by Prof. W. M. Fontaine, of the University of Virginia, who accompanied him for twenty-five days. The object of this investigation was the verification of important hypotheses advanced by various geologists who had studied the formation in question. In September Professor Ward visited the Black Hills of South Dakota, for the purpose of investigating the mode of occurrence and the geologic position of certain fossil cycadean trunks that had come to the National Museum from that locality. He was successful in his efforts, and obtained considerable important data upon the relations of the Cretaceous formations about the Black Hills.

In addition to the work mentioned Professor Ward identified more or less material sent in from the field by various geologists.

Owing to the greater portion of my time being taken up by duties relating to the administration of the branch, I have been able to give but little attention to field or office work in geology or paleontology. Early in October I made a geological reconnaissance of the Green Pond mountain district in the northern portion of the State of New Jersey, conjointly with Dr. J. C. Smock, State geologist. On the completion of this, I began an examination of the lower Paleozoic rocks between the Delaware and Susquehanna rivers, in Pennsylvania. On returning to Washington, prepared a short article on the Pennsylvania work. October 31, I left Washington for eastern Tennessee, for the purpose of making a reconnaissance, with Mr. Arthur Keith, of the great Ocoee formation. Numerous sections of the Ocoee formation were examined from day to day on the East Fork of the Little Pigeon River in the vicinity of Johns Cove, on the Pigeon River above Newport, Tenn., and along the gorge of the French Broad River below Del Rio. November 11, we returned to Knoxville, and from there drove to the narrows of the Little Tennessee River for the purpose of examining the roofing-slate region in the lower portion of the Ocoee series. Returning to Knoxville November 14, I proceeded to Atlanta, Ga., to consult with the State geologist in relation to joint geologic work in Georgia. Arrangements were made for cooperation in the investigation of the phosphate deposits of southern Georgia and in the preparation of certain topographic maps in the gold belt of northeastern Georgia.

Whenever opportunity offered during the year, attention was given to the study of the Lower and Middle Cambrian faunas of North America. Little progress was made in this, however, owing to the limited time at my disposal for this purpose.

Mr. Charles Schuchert, assistant paleontologist, was placed in charge of the laboratory of Paleozoic paleontology in the National Museum. The following extracts are made from his report of field and office work.

Under instructions from you, I left Washington for Rome, N. Y., July 14, and from there proceeded to Madison, Wis., and to all the important localities of Middle and Upper Cambrian rocks in the States of Wisconsin, Minnesota, and Iowa, for the purpose of making a complete collection of the fossils characteristic of the St. Croix terrane. I was engaged in this work until September 28. Fourteen boxes of fossils were collected, and the correct stratigraphic position of the various faunal horizons determined.

On October 17 instructions were received from you to make as complete a collection as possible of the Lower Cambrian fossils occurring around York, Pa. Prof. A. Wanner, city superintendent of public schools, gave me important assistance, and I was able to bring away three barrels and four boxes of fossils.

The balance of the year was spent in the laboratory preparing for study the collections made in the field and much other Cambrian material assembled in previous years by Mr. C. D. Walcott.

In addition to these collections this department has received from Messrs. Walcott, Diller, Hague, Dale, Weed, Turner, Stanton, Prosser, and Bufford, of the Survey, forty boxes and nine drawers of fossils, making the entire accession for the year fifty-eight boxes, three barrels, and nine drawers of fossils. All of this material, with the aid of Mr. William Whipple, of the National Museum, has been properly recorded upon the Survey register, and is now stored in drawers in the National Museum, awaiting detailed studies.

Through the U. S. National Museum forty-two lots of fossils were received for determination, all of which have been duly reported upon to the Museum authorities.

Special reports as to the age of certain fossils submitted were made to Messrs. Diller, Hague, Weed, Dale, Turner, and Safford.

Considerable time was also given to the preparation of a catalogue of the illustrated Paleozoic fossils now preserved in the U. S. National Museum. Many of the older types, particularly those of Mr. F. B. Meek, had never received distinguishing marks, thus rendering it difficult to determine what specimen of a lot had been figured. This catalogue now numbers one thousand lot entries and will be soon completed. About one week of my time was given to unpacking and arranging for exhibition in the department of geology, U. S. National Museum, the Paleozoic collections exhibited by the Survey at the World's Columbian Exposition.

During your absence from the Survey office in July, August, and September most of my time was devoted to administrative work in connection with matters left in my charge by you, and in May and June my entire time was consumed in attending, at your request, to the general administration of the Survey.

In transmitting this, my last, report to you as Director of the Geological Survey, I desire to express my sincere regret at the severance of your relations with the Survey as its official head. During the fourteen years of my connection with the bureau I have always received at your hands the fullest and kindest consideration and have been afforded every opportunity for carrying forward my scientific work. Whatever of success has attended my efforts is owing largely to your aid and encouragement.

Yours, respectfully,

CHAS. D. WALCOTT,
Geologist in Charge of Geology and Paleontology.

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

REPORT OF MR. G. K. GILBERT.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of the work in my charge for the year ending to-day.

WORK ON CORRELATION ESSAYS.

At the date of my last annual report the series of essays was complete, with the exception of one on the Pleistocene, by Prof. T. C. Chamberlin; a thesaurus of American geologic names, by Mr. W. J. McGee; and a discussion of the principles of correlation, by myself. None of these essays has yet been completed, and I regret to say that the work upon them has made small progress during the fiscal year. Professor Chamberlin, engrossed by new, important, and varied duties, has not found time for the preparation of his essay. Mr. McGee resigned his position in the Survey at the close of the preceding fiscal year, and although he has retained his interest in geologic work and has cooperated with the geologists in many ways, he has not resumed the preparation of the thesaurus. As his work for the future is to lie in other fields, it seems best that the material he has gathered be turned over to another, by whom the work may be continued and completed, and attention has been given to the selection of his successor in the work. The requirements for its successful prosecution are so exacting that it is difficult to find an individual who is well qualified and who is not already committed to other work of importance; but there is reason to hope that in the course of a few months the work can be placed in good hands. To the subject of my own essay I have devoted much thought. Before discussing the principles which should guide the work of correlation, it has seemed proper to ascertain the principles which actually do guide it; and as these are formulated by a few writers only, the attempt has been made to infer them from the literature of practical correlation. This implies the examination of a large body of literature, and such examination has occupied much time.

FIELD WORK IN COLORADO.

Early in the fiscal year I was instructed by you to take up the study of the geology of the Great Plains. As Mr. R. T. Hill was already engaged in that study, it was thought best that we should work together for a few weeks for the purpose of establishing a basis for the coordination of our work. A large amount of study has already been given to the region by the geologists of the country, official and unofficial; but the area is so vast that a thorough understanding of the structure has been reached only in limited districts, and but a small amount of final areal work has been done. Under these circumstances it appeared best to begin with a piece of local detail work, selecting a district which promised to exhibit the main points of the stratigraphy. The district chosen was the Pueblo atlas sheet, including a portion of the foothills of the Rocky Mountains, and was already known to exhibit an extensive section of Cretaceous strata.

Early in July I left Washington for the field, being joined in Chicago by Mr. Hill. We stopped en route at Topeka, to confer with Professor Prosser, and reached Pueblo on the 16th of July. Immediate attention was given to securing a camp outfit and field party. Wagon and harness were transferred from the Western Division of Topography, and other materials and supplies were purchased. Six horses were hired from Mr. Daniel O'Neill, and he was engaged to accompany us as teamster. James O'Connell was hired as cook. We went into camp on the 19th of July and continued until the 31st of October. Mr. Hill remained with me seven weeks and returned east early in September. Shortly before his departure I was joined by Mr. F. H. Newell, topographer in charge of hydrographic work, who remained with me two weeks. Being engaged in a broad study of surface and subterranean waters with reference to irrigation, he found it advantageous to study with me the local stratigraphy and the artesian problems of my district. While with me he gave special attention to the Dakota sandstone, regarded as a receiver, transmitter, and storer of artesian water, studying its stratigraphy and structure and investigating its relation to the water supply of streams which traverse it. He also aided me in my areal work.

The field work accomplished the delineation of the areal geology of the sheet and the complete determination of the geologic structure. Attention was given to the recognized mineral products, building stone, limestone flux, and artesian water, and search was made for fire clay. Data were acquired for the construction of a map showing by contours the depth beneath the surface of rocks affording artesian water, and approximate indication can be made of the extent of the artesian district.

About thirty boxes of fossils were collected, chiefly from Cretaceous formations, and it is believed that these will serve not only to correlate the local formations with those from which sections have been made in other parts of the Plains district, but also to enlarge somewhat the known faunas of the formations. The collections include representations of the rocks of the area and a few minerals. A few objects of archeologic interest were also gathered, and these have been transmitted to the Bureau of American Ethnology.

The Pikes Peak sheet, upon the survey of which Mr. Whitman Cross was engaged, lies northwest of the Pueblo sheet, touching its corner. For the purpose of correlating our work Mr. Cross invited me to join him for a few days, and this invitation I gladly accepted. We traversed together portions of his sheet and my own and also of the Canyon City and Colorado Springs sheets, which adjoin them both.

The conduct of the geologic field work showed that the topographic map required revision, and application was made therefor. Near the end of October I was joined by Mr. R. O. Gordon, topographer, detailed for the work of revision by Mr. A. H. Thompson, geographer in charge of the Western Division of Topography, and he began work at once, making use of my camp outfit, which he afterwards stored for me in Pueblo.

OFFICE WORK.

The collections of fossils, rocks, etc., have been arranged, and the fossils have been transmitted to the paleontologic branch of the Survey. Six samples of fire clays and five samples of shales were transmitted to the chief chemist, under whose directions examinations and analyses were made. The shales analyzed have not yet been put to economic use, but as they exist in immense bodies it was thought best to make a record of their constitution in the interest of those growing industries which utilize our argillaceous rocks. The examination of the fire clays served to show that further search for deposits of this character will be warranted, and, with your permission, an article was published in a local paper, the Pueblo Chieftain, describing the stratigraphic relations of the fire-clay horizons, and indicating the limited districts to which careful attention might advantageously be given.

In Bulletin No. 78 Prof. F. W. Clarke has published an estimate of the relative proportions of the various elements and compounds in the earth's crust, basing his conclusions on the averages of certain bodies of analyses. In studying his paper it occurred to me that if a similar statistical method were applied to the sedimentary rocks, it might lead to valuable estimates, first, of the total quantity of the sedimentary rocks, and, second, of the relative abundance of the principal classes of the sedimentary rocks, viz, sandstones, limestones, and shales. In a preliminary study it was found that the data concerning shales are not abundant, and with your consent I undertook to meet this difficulty, so far as this particular inquiry is concerned, by sampling the shales of the United States and having one or more analyses made of composite samples. To this end I have invoked the aid of a large number of correspondents, whom I have asked to send me representative shale samples from their several districts, with data as to their thickness, age, etc. A large number of samples have already been received, and it is believed that by the autumn, after the geologists of the country have made their summer excursions, the series of specimens will be adequate.

Some time has also been devoted to the development of a plan for the mechanical solution of problems in least squares. The most important body of computations employing the method of least squares is that for the adjustment of triangulation, and as nearly all this work is done by the Government there would manifestly be an advantage to the Government if the labor could be materially abridged by the use of machinery. It therefore seemed not improper, despite the fact that I am not now occupied with triangulation, that I should attempt to develop an idea which gave promise of accomplishing such a result. In this attempt I was greatly aided by the friendly advice of Mr. John W. Osborne, the inventor, and material progress has been made in the development of a plan for a practical machine.

WORK IN WESTERN TENNESSEE.

I regret to say that the report by Prof. James M. Safford on the geology of the Wells Creek basin has not yet been submitted in final form for publication. The time which Professor Safford had expected to devote to it has been consumed partly by sickness and partly by special work that he was called upon to perform for his State. He hopes to be able to complete the report at a very early date.

WORK IN CONNECTICUT.

In the mapping of the Newark formation of Connecticut by Prof. W. M. Davis, of Harvard College, field work had been practically completed the previous year. This year he has given such time as other duties permitted to the completion of the final drafts of the maps and the preparation of descriptive texts, and in this work he has been assisted by Mr. L. S. Griswold. An account of the structural relations of the formation along its eastern border, by Messrs. Davis and Griswold, was published in the Bulletin of the Geological Society of America (Vol. V, pp. 515-530).

WORK IN KANSAS.

Arrangement was made with Prof. C. S. Prosser, formerly assistant paleontologist on the Survey and now professor of natural sciences in Washburn University, Topeka, Kans., to cooperate with the Survey by spending a portion of his leisure on the areal geology of the State, and this work was placed under my supervision. After due consideration the Cottonwood Falls sheet was selected for initial work. Professor Prosser took the field July 17 and continued his work until September 25, making a complete determination of the stratigraphy of the area and running out several of the more important formation boundaries. Field work was resumed last month, and the areal geology of the sheet was completed.

In March and April two short excursions were made to the valley of the Kansas River, for the purpose of repeating certain observations by Meek and Hayden and by Broadhead, and thus establishing a stratigraphic connection between the rocks of the Cottonwood Falls sheet and those which have been described in the more important published sections. The data thus gathered have been used in the preparation of a paper on the "Kansas River Section of the Permo-Carboniferous Rocks of Kansas," to be published, with official permission, in the Bulletin of the Geological Society of America.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist.

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

REPORT OF MR. C. W. HAYES.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit herewith my report for the year ending this day.

A little over four months has been spent in the field and the remainder of the year in office work. I took the field July 1, accompanied by Cyrus C. Babb as assistant. During the whole of July and a part of August I was engaged in making a thorough revision of portions of the Rome and Fort Payne atlas sheets, in Georgia and Alabama. Previous study of this region had revealed some peculiar types of structure having considerable scientific interest, but much obscurity remained in regard to the details. Special attention was given to the study of this complicated structure, and much of the obscurity was cleared up, so that a fairly complete history of the vicissitudes through which the region has passed has been made out. The results of this work were embodied in a paper on the "Geology of the Coosa Valley in Georgia and Alabama," read before the Geological Society of America and published in the bulletin of that society. This is a preliminary paper, to be followed by a thorough discussion, now in course of preparation.

Considerable attention was also given to the economic geology of the region. It contains the largest known deposits of bauxite in the

United States, and the only ones at present worked. The recent utilization of this mineral as an ore of aluminum, and the fact that very little was known of its mode of occurrence and origin, rendered the study of these deposits extremely interesting, and the conclusions reached should be of service in directing search for other deposits and in the economic working of those already known. The results of this study of the bauxite were embodied in a paper on the "Geological Relations of the Southern Appalachian Bauxite Deposits," read before the American Institute of Mining Engineers, and published in the Transactions; also in an article on "Bauxite," published in the Mineral Resources of the United States for 1893.

The latter part of August and most of September were spent in mapping the geology of the Sewanee atlas sheet, in Tennessee. The structure of this region is comparatively simple, and the greater part of our time was spent in a study of its economic geology, particularly the character and distribution of its coals. Practically all natural or artificial exposures of which we could learn were visited, and many sections of the coal-bearing formations were measured. The data obtained form the basis for a fairly complete map of all workable coal beds in the region. The most important coal is the Sewanee seam, which lies in small isolated areas in the highest portions of the plateau. These areas were carefully examined, and the geologic map on which they are represented will be an important factor in directing future development in this region.

At the end of September camp was disbanded and Mr. Babb returned to Washington, while I spent a part of October in revision of portions of the Dalton atlas sheet.

From October to June I was engaged in office work, which consisted mainly in the reduction of field notes, the final revision of atlas sheets for publication, and the preparation of papers embracing the economic and scientific results of the previous field season. The descriptive text has been prepared for four folios, of which one has been published and three are in press.

I have been engaged for the past year and a half, in company with Mr. M. R. Campbell, in the study of problems presented by the relief and drainage of the southern Appalachian region. The results of this study have been published in a joint paper in the National Geographic Magazine entitled the "Geomorphology of the Southern Appalachians."

During a part of June I have been engaged in the investigation of the phosphate deposits recently discovered in middle Tennessee, and have a report on them in preparation.

Very respectfully submitted.

CHAS. WILLARD HAYES,
Assistant Geologist.

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

REPORT OF MR. ARTHUR KEITH.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of progress for this fiscal year.

From the beginning of the year until November 15 I was occupied in field work in Tennessee and North Carolina. During the remainder of the year, excepting a period of field work from April 27 to May 2, I was occupied in office work.

I was assisted by Mr. H. B. Goodrich during the entire field season and during three months of the office work. From July 24 until September 25 I was assisted by Mr. H. B. C. Nitze, of the North Carolina geological survey. Mr. David White, of the U. S. Geological Survey, assisted me from October 11 till October 30 in stratigraphic work and in collecting coal plants in the Briceville basin. My work was prosecuted almost entirely with a camp outfit.

My field work consisted mainly of the collection of data for areal maps, structure sections, and descriptions of atlas sheets, but comprised also the study of new and undetermined series of strata. For these ends, measures of the rock thickness were obtained and observations of dip and nature of strata were made, mineral deposits were located and examined, rocks were searched for fossils, and specimens of rock were collected. Areas on different atlas sheets were completed as follows:

	Square miles.
Roan Mountain, Tenn.-N. C	900
Cranberry, N. C	50
Nantahalah, N. C	400
Murphy, Tenn.-N. C	50
Briceville, Tenn	1, 000
Mount Guyot, Tenn.-N. C	75

The results attained by my field season were, in the main, the completion of field work on the Roan Mountain, Nantahalah, and Briceville atlas sheets; the development of two new series of strata, a crystalline Archean series in North Carolina and the coal-bearing series of the Briceville region in Tennessee; the mapping of the magnetite belt of Cranberry, N. C., and its continuation, the hematite belt of Iron Mountain in Tennessee and the corundum belt of the Nantahalah region in North Carolina; and the discovery of the first fossil remains in the great Ocoee series of North Carolina, Tennessee, and Virginia. As yet these remains are too indefinite to fix the age of this series of rocks, but they furnish a clue which will probably be of great value.

The work in the office has been of two classes: the compilation and drafting of notes, maps, and structure and stratigraphic sections, and the preparation of manuscript to accompany the atlas sheets and special reports. My notes for the entire season have been examined, adjusted, and platted upon the atlas-sheet bases up to date in all cases, except the Nantahalah sheet, which is now being completed in the topographic division. Columnar sections have been drawn for the Harpers Ferry, Knoxville, Greeneville, and Loudon atlas sheets. A drainage map of the southern Appalachians has been compiled for use as a base map, on a scale of 25 miles to the inch.

I have prepared and submitted for the Fourteenth Annual Report a paper on "The Geology of the Catoctin Belt." In this was treated the mountain belt extending from Pennsylvania into Virginia, and its development and phases as a continent; its rocks—volcanic, igneous, and sedimentary—were classified, their structure and metamorphoses worked out, and their methods and periods of degradation described. Descriptive text to accompany the Harpers Ferry, Knoxville, Greeneville, and Loudon sheets, typical of the entire area of my work, has been completed. I have collaborated with Mr. C. W. Hayes and Mr. M. R. Campbell in the preparation of the general text to accompany Appalachian atlas sheets.

About 150 thin sections of rock specimens from North Carolina and Virginia were studied by me, in connection with my atlas-sheet work, and the results have been embodied in the atlas sheets as far as possible at present.

Special reports have been presented showing in detail the nature and cost of my work for the field season, and plans for the ensuing year have been prepared.

Very respectfully,

ARTHUR KEITH,
Assistant Geologist.

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

REPORT OF MR. M. R. CAMPBELL.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report for the fiscal year ending June 30, 1894.

FIELD WORK.

According to instructions, I entered the field on July 1, 1893, with two assistants, Messrs. David White and Harry Landes, and the requisite number of camp hands. After outfitting at Wytheville, Va., we began areal work on the Dublin atlas sheet. The pressure of work in other directions did not permit complete mapping, but a thorough reconnaissance was made of the entire sheet. Mr. White obtained a large collection of fossil plants from the Lower Carboniferous beds at the

Altoona mines near Pulaski and at the various mines in Price Mountain east of New River.

After completing the Dublin sheet, camp was moved down New River to Hinton, to enable us to study the section of the conglomerate series exposed in the river gorge below that place. During the few days at our disposal Mr. White and I made excursions down the river to Nuttall and Prince and secured a fair amount of fossil-plant material, although we were greatly retarded by heavy rains and high water.

From Hinton we proceeded to the Pocahontas-sheet area, which we worked very thoroughly, especially the northern portion, embracing the Pocahontas or Flat Top coal field. This field is without complications, and most of the outcrop of the great Pocahontas seam has been followed with transit and level by the engineers of the various land companies. Their information was placed at our disposal, thus aiding us greatly in our work. In this field, also, Mr. White collected fossil plants from the various members of the conglomerate series and by their evidence assisted materially in correlating horizons throughout the field. His work is full of promise, and I believe it will prove not only of value scientifically, but also of great assistance in the practical work of correlating the coal seams.

Upon the completion of the sheet on October 8, Mr. White was transferred to Mr. Keith, and Mr. Landes and I began work on the Bristol sheet, one-third of which had been mapped by me in 1891. Before we could complete it the weather became too severe for camp life, and on October 31 we disbanded. I finished the sheet alone, and on November 25 reached Washington.

OFFICE WORK.

Aside from the routine work of the office, I have prepared or assisted in preparing several papers, which are the direct result of field work in this or previous seasons. A paper describing the peculiar structure of the region along the line of the Norfolk and Western Railroad from Christiansburg to Max Meadows was presented at the Boston meeting of the Geological Society of America and published as a bulletin of that society under the title of "Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia." Later Mr. C. W. Hayes and I completed a paper on the "Geomorphology of the Southern Appalachians," which was published in the National Geographic Magazine. This paper is the result of several years' study of the surface features of the region in question, and expresses our idea of its post-Paleozoic history as interpreted from its physiographic features. In the same line of study are an article by myself on "Tertiary Changes in the Drainage of Southwestern Virginia," published in the American Journal of Science, and a paper in preparation on "The Influence of Orogenic Movements on the Drainage of the Appalachians." My latest work has been to prepare for publication the geologic boundaries, structure and columnar sections, and text of the Pocahontas sheet, and the text of the Estillville sheet. The maps of the latter sheet are nearly ready for printing and will soon appear in the regular publication of atlas-sheet folios.

Respectfully submitted.

M. R. CAMPBELL,
Assistant Geologist.

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

REPORT OF MR. N. H. DARTON.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report for the fiscal year ending to-day.

The greater part of the year was devoted to field work in the State of New York and the preparation of maps and preliminary reports on the results. Supplemental field work was done in the Coastal Plain region of Maryland and Virginia and in the Green Pond-Skunnemunk belt in New Jersey and New York. Descriptions were prepared to accompany several geologic atlas sheets, several papers of a scientific nature have been written, and work has been done to complete the index for the "Authors' Catalogue of Contributions to North American Geology from 1753 to 1891."

WORK IN NEW YORK STATE.

Field work in New York was carried on in cooperation with the State geological survey under the direction of Prof. James Hall, State geologist. It included the mapping of the region adjoining the Mohawk Valley and extending northward to the southern edge of the Adirondacks, and the counties of Albany and Ulster. Field work was begun early in July and continued until the first week in November. Two classes of work have been done in different areas, reconnaissance and detailed mapping. These were so apportioned as to give the most useful results. In the region extending from near Albany to Ellenville, detailed maps were prepared of the region previously reconnoitered, and the reconnaissance was extended some distance westward into the Catskill Mountains and southeastward toward Newburg. In portions of Albany and Green counties topographic maps were available as bases for geologic work, but in other regions it was necessary to prepare sketch maps upon which the geology might be platted. The notes thus obtained may hereafter be adjusted to the topographic bases when the latter are ready. Toward the northeastern corner of Albany County a reconnaissance topographic map was prepared, with 50-foot contour lines, based on aneroid levelings.

During the fiscal year the area of reconnaissance was 2,500 square miles, and that of detailed geologic surveys was 900 square miles. The following sheets were mapped in detail:

Rosendale.	Fonda (in part).
Berne.	Catskill (in part).
Utica.	Coxsackie (in part).
Amsterdam.	Canajoharie (in part).
Little Falls (in part).	Kaaterskill (in part).

The margins of areas adjacent to those embraced in the above sheets were also mapped. In the Albany-sheet area, which was mapped last year, notes were taken for the representation of the Champlain deposit, by crossing the area in the course of other work. The area of the Rosendale sheet includes beds which are extensively quarried for cement. The geologic structure of these beds is somewhat complicated, and special attention was given to the region. In other areas also there are economic resources, which were studied. Along the Hudson, brick clays and molding sands are important products, and elsewhere limestones and millstones are extensively quarried. It is the object of these surveys to promote the development of these resources. This work being done under the direction of Prof. James Hall, State geologist, the preliminary maps and reports have been placed at his disposal for publication, and will be included in his annual report for 1893 under the following titles: "A Preliminary Report on the Geology of Ulster County;" "A Preliminary Outline of the Geology of Albany County;" "A Preliminary Report on the Faulted Region of Fulton, Montgomery, Saratoga, Herkimer, and Adjacent Counties;" "On the Stratigraphy of the Helderberg and Associated Formations in Eastern New York."

About three months' time was spent in writing these reports. They were completed at the end of January, 1894, and submitted for transmission to Professor Hall.

A portion of the field work was devoted to continuation of the study of the Green Pond-Skunnemunk Mountain belt in New Jersey and New York. The belt is a narrow basin of Paleozoic rocks included in the ancient crystallines, and comprises a number of formations ranging in age from middle Cambrian to middle Devonian. The structure and stratigraphy are complicated. A preliminary notice of the results of these studies was, by your permission, presented to the Geological Society of America and published in one of its bulletins.

WORK IN THE COASTAL PLAIN REGION.

In continuance of field work in the Coastal Plain of eastern Maryland and Virginia, I have made many short trips at various times during the spring and summer. These included examinations in the vicinity of Richmond and on the northern portion of the Petersburg sheet, with special study of the distribution of the marl beds. Observations were continued from time to time about Washington to obtain additional details for a new edition of the Washington sheet. Work has also been extended in eastern Maryland for additional notes and photographs. In the Coastal Plain region the geologic boundaries have now been drawn upon the following atlas sheets:

Washington.	Drum Point.
Baltimore.	Annapolis.
Fredericksburg.	Relay.
Prince Frederick.	Owensville.
Wicomico.	Sharps Island.
Brandywine.	North Point.
Point Lookout.	Richmond.
Piney Point.	Bermuda Hundred.
Montross.	

In the Coastal Plain the problem of the occurrence of artesian water is of much importance, and attention has been given to the collection of all available data. Many samples of borings have been received, which throw new light on the underground geology of the region, and afford a basis for prediction of the occurrence of water in many districts. A preliminary account of these studies was given, with your permission, to the American Institute of Mining Engineers at the Virginia Beach meeting, and a more extended report on the subject is now in course of preparation. Information has been supplied in response to inquiries of various persons in regard to artesian waters and other economic products of the Coastal Plain region.

Respectfully submitted.

N. H. DARTON,
Assistant Geologist.

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

REPORT OF PROF. T. NELSON DALE.

U. S. GEOLOGICAL SURVEY,
Williamstown, Mass., June 30, 1894.

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

From July 5 to October 5 I was engaged in field work on the Troy sheet. Two days of that time, however, were spent in completing the Berlin sheet section. Mr. Louis M. Prindle assisted me in field work on the Troy sheet from July 7 to October 1.

From October 5 to January 13 I was engaged in completing the Pittsfield and Berlin structure sections and their descriptive and general texts. Since January 13 my time has been spent in the preparation of the material for the Troy atlas sheet. During the latter part of March and early in April I worked nearly two weeks at the office of the Geological Survey in Washington.

Very respectfully,

T. NELSON DALE,
Geologist.

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

REPORT OF PROF. GEORGE H. WILLIAMS.[1]

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., June 30, 1894.

SIR: I have the honor to submit herewith the following report of my work upon the crystalline rocks of southern Pennsylvania, Maryland, and northern Virginia during the fiscal year 1893–'94.

FIELD WORK.

Mapping of the crystalline areas has been carried on within the limits of the Gunpowder, Laurel, West Washington, and Frederick atlas sheets. The West Washington sheet has been completed, and, with the accompanying text, turned into the Survey office. The Gunpowder sheet is about two-thirds completed, and work is now in progress upon the Laurel and Frederick sheets. A study of certain Archean rocks in the neighborhood of Philadelphia has also been carried on, to obtain additional light upon problems which are being investigated.

LABORATORY WORK.

The material which has been collected in the field within the limits above described has been to a large extent sectioned and studied microscopically, while chemical analyses of several of the important types have also been made in the Washington office. Mr. G. P. Grimsley has made a thorough study of the granites occurring on the north shore of the Susquehanna in Cecil County, and has conclusively established their igneous origin.

In cooperation with the geological survey of North Carolina, Mr. J. V. Lewis has investigated the corundum-bearing chrysolite rocks of the western part of that State.

REPORTS.

During the year I have had the honor to transmit for publication a paper by Prof. C. R. Keyes on "The Origin and Relations of Certain Maryland Granites," accompanied by an introduction by myself, dealing with the general relationship of these rocks within the whole Appalachian crystalline belt. I have also transmitted an illustrated paper on "The Ancient Volcanic Rocks of South Mountain, Pennsylvania," by Miss Florence Bascom.

Progress has been made in the preparation of reports upon other investigations, which will be hereafter submitted for publication.

Very respectfully,

GEORGE H. WILLIAMS,
Assistant Geologist.

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

---

[1] While this report was in preparation for the press, news was received at the Survey of the sudden death of Dr. Williams, at Utica, N. Y., on July 12, 1894.

REPORT OF PROF. W. B. CLARK.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., June 30, 1894.

SIR: I submit herewith a report of the investigations conducted by me during the past year under the auspices of the U. S. Geological Survey.

The work has been carried on in cooperation with the State geological survey of New Jersey, and the field of operations has embraced the Cretaceous and Tertiary area of that State.

The work had so far progressed at the close of the previous year that a reconnaissance of the district had been made and two atlas sheets (Sandy Hook and New Brunswick) had been finished in a preliminary way. Some problems relating to the Tertiary deposits could not at that time be satisfactorily worked out, although their solution has since been practically reached. Very little work will therefore be required to prepare for publication the two sheets named.

During the present year the Cassville sheet has been mapped, but the increase in the amount of Tertiary and post-Tertiary deposits in passing southward has rendered the establishment of the boundary lines of the Cretaceous formations a work of painstaking examination. The work was completed and the atlas sheet is now ready for publication.

A new system of nomenclature has been established, as it was deemed necessary to introduce place names for the inadequate lithological terms of earlier writers, although the latter will be found serviceable as economic equivalents. Some of the divisions established by Professor Cook, the late State geologist, to whom we are indebted for the first clear understanding of the coastal series of New Jersey, have been either discarded or modified, although the majority are retained with the changed nomenclature.

The writer has had associated with him in this work Messrs. H. S. Gane and R. M. Bagg, students in the Johns Hopkins University. The mapping of the Cassville sheet has been to a large extent done by Mr. Bagg.

WILLIAM B. CLARK,
Geologist.

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

REPORT OF PROF. J. E. WOLFF.

HARVARD UNIVERSITY,
Cambridge, Mass., June 30, 1894.

SIR: I have the honor to submit the following report of work during the fiscal year just closing.

Field work was carried on by myself in the Archean highlands of New Jersey during July, August, and September. It was entirely devoted to the areal geology of the Lake Hopatcong sheet of the Geologic Atlas of the United States, and was practically completed for somewhat over 100 square miles, the total area of the sheet being about 233 square miles. In doing this work the method of previous years was continued—that of indicating the exact location on the map of specimens and observations by coordinates, so that they become a permanent record. Studies were made of the iron mines, as they were reached in the progress of the work, and some attempt was made to note, for the future map, masses of rock of exceptional value for road material or building-stones.

At the request of the State geologist of New Jersey, and by permission of the Director, a paper was prepared during the winter for the annual report of the New Jersey geological survey, entitled, "On the Geological Structure in the Vicinity of Hibernia, Morris County, New Jersey, and its Relation to the Ore Deposits," illustrated by a geological map and sections, in which the writer's reasons are given for the belief that the Hibernia ore bed should be looked for beyond its present northernmost workings and in an unexpected direction. This conclusion, of considerable possible economic importance, since the Hibernia ore bed is one of the largest in the State, was reached entirely by careful areal study of the rock structure of the region.

Yours, very respectfully,

J. E. WOLFF,
Assistant Geologist.

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

REPORT OF MR. GEORGE H. ELDRIDGE.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following statement regarding work in my charge in Wyoming and Florida during the fiscal year just closing.

During the period from July to September, inclusive, by your direction, I made a reconnaissance in northwest Wyoming, embracing the Big Horn and Wind River basins and adjoining mountain and prairie regions, with a view to determining the extent and value of the coal deposits, and incidentally to acquire information of such other economic resources as time and route permitted.

Investigations were begun east of the Big Horn Range, in the vicinity of Sheridan, and extended along the western edge of the Powder River coal field from its southern extremity to the Montana-Wyoming line.

The Big Horn Range was crossed at two points, 60 miles apart, Cloud Peak being midway between. On the northern route the new gold prospects of Bald Mountain, a few miles south of the Montana line, were visited. The lofty points, and the open character of the country generally, permitted clear views of stratigraphy and structure for much of the range length and far out across the prairies at either base. The broad belt of folded strata along the west base of the range, which is of especial importance in respect to both coal and petroleum, was examined, and the formation outlines and general structure were delineated.

The low divide between the Big Horn basin and the valley of the Yellowstone was traversed in passing from the Big Horn Range to the Red Lodge (Rocky Fork) coal district at the base of the Absaroka Range in Montana.

The examination of the Red Lodge coals was for the particular purpose of comparing with them those of the Big Horn and Wind River basins, the mines at Red Lodge being extensive, and thus affording views not only of outcrops but of depth.

From Red Lodge the route of reconnaissance was along the west side of the Clarks Fork Valley and the Big Horn basin. In the latter, in the vicinity of Sunshine post-office, was encountered a coal field of considerable promise, hitherto known only to the few settlers of the region, and wholly undeveloped.

From Sunshine a trip was made into the heart of the Shoshone Mountains, to the head of Wood River and Grey Bull, and the structure and formations of the range were examined.

The Owl-Rattlesnake Range, separating the Big Horn and Wind River basins, was crossed just west of the Wind River canyon, and again opposite the Mail Camp, 30 miles farther west, and the formations and structure in the broad belt of folded strata on either side were delineated.

The route of reconnaissance crossed the Wind River basin, both along the river valley and on the meridian of Fort Washakie to the west. Especial attention was paid to the important oil belt along the base of the Wind River Range, and the structure of the included formations was determined. The coal field near Lander was also examined.

In this reconnaissance the economic materials that were encountered along the route, and therefore received special attention, were coal, petroleum, building-stones, clays, soils, and artesian waters.

The period from October to February, inclusive, was occupied in the

Washington office in preparing a report upon the reconnaissance in Wyoming, which has since been submitted.

During the period from March to June, inclusive, by your direction, work upon the phosphate fields of Florida was resumed. The work has consisted of the delineation in detail of the phosphate-bearing formations, examination of the extent and value of the deposits, acquirement of all geologic facts that may bear upon their origin, and a continuation of the study of mining methods and the subsequent preparation of the rock for market. Much of the time has been spent in the fields of north and west Florida, which have been extensively opened by pits since my last visit in the spring of 1891. The work in this section of the State is nearly complete. In south Florida the work has been advanced, but in less areal detail than in north and west Florida.

All obtainable information bearing on the origin of the deposits and their relation to the associated formations having been collected, it is believed that important distinctions can be made in their manner of geologic development.

Incidental to the Florida work, an examination in southern Georgia was made for phosphate deposits of economic value, but without satisfactory result.

I have the honor to remain, sir,

Very respectfully, your obedient servant,

GEO. H. ELDRIDGE,
Geologist.

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

REPORT OF PROF. N. S. SHALER.

HARVARD UNIVERSITY,
Cambridge, Mass., June 30, 1894.

SIR: I have the honor to submit herewith a report on work during the year ending this day.

I have directed the undertakings almost wholly toward advancing the delineation of the surface geology of the New England States, the aim being to complete the work in the three southern States of this field and to keep the work in the northern commonwealths as near as possible apace with the progress of the topographic survey. Four assistant geologists have been employed in this task; of these, only Mr. J. B. Woodworth has been continuously engaged in the work.

These gentlemen have been employed as follows:

Mr. J. B. Woodworth has been engaged in the field in the region about Narragansett Bay. He has also spent some time in revising the work of assistants done this year in certain parts of Connecticut and Massachusetts, and he has had charge of the office work of the division.

Mr. R. E. Dodge did the field work and prepared the descriptions of the Moosup, Putnam, and Stamford sheets, in Connecticut.

Mr. L. H. Davis prepared the maps and reports of the Bridgeport and Norwalk sheets, in Connecticut, and did some work on those parts of the Pittsfield and Berlin sheets which lie in the State of New York. This task, though it took him beyond the limits of New England, was undertaken in order that the sheets whose area lies only partly in Massachusetts might not be published in an unfinished form.

Mr. G. H. Barton was engaged in completing the delineation of the drumlins in Massachusetts. He was directed to extend his work so as to include the portion of the area of southern Vermont and New Hampshire which is shown in the northern tier of Massachusetts sheets. The field work connected with the delineation of drumlins is now completed for the last-named State.

The office work has been as follows: I have myself prepared and forwarded to you a memoir, intended for publication in the Fifteenth Annual Report of the Director, entitled "Preliminary Report on the Geology of Common Roads." By direction from the office in Washington, information has been given to inquirers concerning many points in the surface and under geology of the field included in my work. These inquiries have included various questions relating to water supply, drainage, and the use of gravels for filtration, to sources of supply of railroad ballast, materials for roadmaking, and clays for pottery purposes, particularly those on the island of Marthas Vineyard, as well as a number of questions concerning peat deposits, some of which have come from persons in France and in Canada.

The following-named geologic maps, with their accompanying descriptive texts, embracing certain areas in Massachusetts and Connecticut, have been sent to Washington for printing: Abington, Barre, Barnstable, Falmouth, Nantucket, Provincetown, Salem, Sheffield, Worcester, and Webster. Other sheets to the number of sixty, with their accompanying descriptions, are ready for publication and will be forwarded whenever desired for that purpose. They are at present retained in this office in order that they may from time to time be amended, and also for the reason that they are convenient for use in answering various inquiries.

During the year the following contributions relating to the work of the division have been published by me: "The Geological History of Harbors," Thirteenth Annual Report of the U. S. Geological Survey, Part II, pp. 93–209; "Pleistocene Distortions of the Atlantic Seacoast," Bulletin Geological Society of America, Vol. V, pp. 199–202; "Relation of Mountain-Growth to Formation of Continents," ibid., pp. 203–206; "Phenomena of Beach and Dune Sands," ibid., pp. 207–212; "On the Distribution of Earthquakes in the United States since the Close of the Glacial Period," Proceedings Boston Society of Natural History, Vol. XXVI, pp. 246–256.

The following have also been published:

By J. B. Woodworth: "Some Typical Eskers of Southern New England," Proceedings Boston Society of Natural History, Vol. XXVI, pp. 197-220.

By G. H. Barton: "Channels on Drumlins, Caused by Erosion of Glacial Streams," abstract in American Geologist, Vol. XIII, March, 1894.

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

N. S. SHALER,
Geologist.

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

REPORT OF PROF. C. R. VAN HISE.

UNIVERSITY OF WISCONSIN,
Madison, Wis., June 30, 1894.

SIR: I beg to submit the following report of work under my charge for the fiscal year ending to-day.

FIELD WORK.

The following persons, besides myself, have been engaged in field work: W. S. Bayley, J. Morgan Clements, H. F. Phillips, and James R. Thompson. The work of the corps has been wholly in and adjacent to the Marquette iron-bearing district of Michigan.

Mr. Thompson has platted in detail certain critical areas about Michigamme and Champion. The regular areal work was done by Messrs. W. S. Bayley, J. Morgan Clements, and H. F. Phillips. By the end of the season they had completed the unsurveyed part of the Marquette district and joined the areas previously surveyed on the north and south. The areal work now finished extends from the Felch Mountain and Menominee districts on the south to Lake Superior or the Cambrian sandstones on the north, and from the Cambrian sandstones on the east to meridian 89° on the west; while west of this meridian parts of sheets have been mapped. As soon as a topographic base is available the atlas sheets can be put in shape for publication.

My own field work, with Mr. H. F. Phillips as assistant for a part of the season, comprised the general structural problems of the Marquette district and the tracing of boundary lines between formations upon maps containing the work of previous seasons. This work could not be accurately done in the first instance because the character of many rocks had to be determined by thin sections before the boundary lines could be finally placed.

OFFICE WORK.

In the office, aside from the routine work, Mr. W. S. Bayley and I have given our entire time to the preparation of a preliminary report upon the Marquette district. Mr. H. L. Smyth has prepared one chapter for this paper. Mr. J. Morgan Clements has given his time to a study of the eruptives of the iron-bearing district. Mr. C. W. Hall has given a small amount of time to the completion of his bulletin upon the Minnesota Valley gneisses and schists. All of the drawing has been done by Mr. F. E. Morrow, and the clerical and typewriting work by Mr. C. K. Leath.

SCIENTIFIC AND ECONOMIC CONCLUSIONS.

Some of the more important results of the year's work have been as follows:

The iron-bearing formations of the Marquette district are confined to three horizons: (1) The iron-bearing formation at the top of the Lower Marquette series; (2) a horizon at the base of the Upper Marquette series, where it is in contact with and has derived the major portion of its detritus from the iron-bearing formation of the Lower Marquette series; and (3) a horizon in the lower part, but not at the base, of the Upper Marquette series. The major portion of the ore is derived from the first two horizons.

In the areal mapping these iron-bearing formations have been accurately delimited, with the result that the first and most important has been found to extend in one place for several miles east of the area where it has heretofore been known to occur.

It has been shown that the various ores and ferruginous rocks of the Marquette district are derived from an original lean cherty carbonate of iron. This fact had already been demonstrated for the Penokee and Animikie districts, but had not been shown for the Lower Marquette rocks, although the likeness of the iron formations of the Upper and Lower Huronian led Irving, myself, and others to believe that the two had a common origin. During the season we have been able to trace all gradations, from the most completely altered phases of ferruginous cherts and jaspers, through the regularly laminated ferruginous slates, to the unaltered iron carbonates, the chain of evidence being not less complete than in the iron formations of the Upper Huronian.

The laws which control the occurrence of ore bodies within the iron-bearing formations of the Marquette district may be summarized as follows: (1) The iron ore always rests upon a relatively impervious basement. This basement may be a shale, a slate, a diorite, a dike, or two or more of these combined. (2) Large ore bodies are found only when the impervious basements are in the forms of pitching troughs. (3) These pitching troughs are particularly likely to bear unusually large ore bodies when the iron-bearing formation has been shattered by folding.

The explanation of the occurrence of iron-ore deposits in these peculiar places lies in the fact stated above, that the original source of the iron ore is a lean iron-bearing carbonate. The ore bodies are largely secondary concentrations produced by downward-percolating waters. Within the troughs the iron-bearing and oxygen-bearing solutions have been converged and mingled, thus precipitating the iron oxide.

It has been ascertained that the folding of the Marquette district is similar to that of the Alps. The central part of the Marquette district is a synclinorium. In the folding of the east-west trough, however, the Archean rocks have been pushed under the Algonkian rocks on both the north and south sides of the trough, and the strata on both sides of the area are in a series of closely compressed, outward-pointing, isoclinal folds. The youngest rocks are in the center of the trough. In the Alps, on the contrary, the central or core rocks are the oldest.

At the east end of the Marquette district is a series of slates, quartzites, and limestones, named the Mesnard series, about the relations of which to the typical rocks of the Marquette area there has been great difference of opinion. We have shown that this series is really a downward continuation of the Lower Marquette rocks of Ishpeming and Negaunee. The Lower Marquette transgression was from the northeast, and the Mesnard series was deposited before the shore-line reached the area where the well-known members of the Lower Marquette series were deposited.

PUBLICATIONS.

During the year there have appeared from the division the following papers:

"The Eruptive and Sedimentary Rocks on Pigeon Point, Minn., and their Contact Phenomena," by W. S. Bayley; Bulletin 108 of the U. S. Geological Survey.

"The Basic Massive Rocks of the Lake Superior Region," by W. S. Bayley; Journal of Geology, Vol. I, pp. 433–456, 587–596, 688–716.

"Some Dynamic Phenomena shown by the Baraboo Quartzite Ranges of Central Wisconsin," by C. R. Van Hise; Journal of Geology, Vol. I, pp. 347–355.

"Summary of Pre-Cambrian North American Literature," by C. R. Van Hise; Journal of Geology, Vol. I, pp. 304–314, 532–541; Vol. II, pp. 109–118. This last may be considered a continuation of the Correlation Papers upon the Archean and Algonkian, Bulletin 86 of the U. S. Geological Survey.

At the Washington office, ready for publication, is the following:

"Preliminary Report on the Marquette Iron-bearing District of Michigan, by C. R. Van Hise and W. S. Bayley; With a Chapter on the Republic Trough, by H. L. Smyth." This paper consists of about 300 pages of typewritten manuscript, accompanied by 5 plates for lithographing, 10 plates for photo-engraving, and 9 figures, and will, it is understood, constitute one of the papers accompanying the Fifteenth Annual Report of the Director.

In preparation are the following:

Monograph on the Marquette Iron-bearing District of Michigan, by C. R. Van Hise and W. S. Bayley; With a Chapter on the Republic Trough, by H. L. Smyth.

Monograph on the Michigamme Iron-bearing District, by C. R. Van Hise, H. L. Smyth, and J. Morgan Clements.

Very respectfully,
C. R. VAN HISE,
Geologist.

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

REPORT OF MR. WHITMAN CROSS.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report concerning the work in my charge during the past fiscal year.

FIELD WORK.

The field work assigned to me for the summer of 1893 was the survey of the district embraced by the Pikes Peak atlas sheet, in Colorado. In the first week of July I procured a camp outfit and organized my party in Denver. The party consisted of four persons—a cook, a teamster, Mr. E. B. Mathews, of Johns Hopkins University, as geological assistant, and myself. The field of work was reached on July 8, and the survey was prosecuted uninterruptedly until October 24, when it was completed. On October 27 the party disbanded at Colorado Springs, and I at once returned to Washington.

The Pikes Peak atlas sheet embraces about 930 square miles, mostly of mountainous territory. Pikes Peak is situated in the northeastern portion of the area, and the Cripple Creek mining district, the most important of the newer gold fields of the country, lies near its center. The district has not been studied geologically since the reconnaissance of the Hayden survey in 1873. The more detailed work has resulted in new conclusions regarding many features of the local geology, and several generalizations are of broad application.

The observations made bear directly upon the questions of the age and mode of origin of the granites and gneisses forming so large a part of the Rocky Mountains. The history of several great periods of sedimentation and orographic disturbance has been outlined by newly observed facts, and many of the phenomena of a great epoch of Tertiary volcanic action, whose products were quite varied and in part very unusual in character, have been determined.

The ore deposits of the Cripple Creek district have been examined in their geological relations, affording a basis for conclusions as to their origin and extent.

OFFICE WORK.

Since returning to Washington, in October, I have been almost exclusively engaged in work pertaining to the geology of the region studied during the field season. The extensive collection of rocks and minerals representing the formations of the Pikes Peak district has been studied and properly cared for. As soon as the topographic map had been engraved the geological sheets of the Pikes Peak folio were prepared and submitted for publication. The descriptive text of the folio has been written, and a bulletin upon the geology of the Pikes Peak district is in preparation. The folio will be ready for distribution during the coming summer.

The granites and gneisses of the Pikes Peak region have been the subject of a special microscopical examination by my field assistant, Mr. E. B. Mathews, fellow in geology at Johns Hopkins University.

During the last few months I have spent some time in the revision and proof reading of the geological maps of the Crested Butte and Anthracite districts in Colorado, which are in process of publication. I have also done some work in connection with the preparation of the monograph upon the Denver coal basin, by Mr. S. F. Emmons, certain chapters of which have been assigned to me.

WORK OF PROFESSOR PENROSE.

A more detailed study of the Cripple Creek mining district and its ore deposits having been determined upon for the coming season, Prof. R. A. F. Penrose, jr., of the University of Chicago, was engaged to assist me and was charged especially with the examination of the ore deposits. In June Professor Penrose visited Cripple Creek to procure material for a chemical investigation of the ores and to make certain preliminary studies in the mines.

PUBLICATIONS.

The following is a list of scientific articles published by me during the past year:

"The Laccolitic Mountain Groups of Colorado, Utah, and Arizona," Fourteenth Annual Report of the U. S. Geological Survey, pp. 157–241.

"Intrusive Sandstone Dikes in Granite," Bulletin Geological Society of America, Vol. V, pp. 225–230.

"Geology of the Cripple Creek Gold-Mining District, Colorado;" read before the Colorado Scientific Society in June, 1894.

Very respectfully, your obedient servant,

WHITMAN CROSS,
Geologist.

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

REPORT OF MR. ARNOLD HAGUE.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to transmit herewith a report of operations conducted under my charge during the fiscal year ending to-day.

FIELD WORK.

In accordance with instructions, I left early in July for Bozeman, Mont., to equip a small field party, for the purpose of determining one or two points of geological interest in the Yellowstone Park and adjacent country, but mainly to complete the geology of the Absaroka Range, in northern Wyoming. On this trip I was accompanied by Mr. T. A. Jaggar, jr., as geological assistant. Mr. Jaggar was a recent graduate of Harvard College and a special student of geology, and he came highly recommended. He remained with me throughout the summer and rendered efficient aid.

Leaving Bozeman July 15 the party proceeded to Livingston, on the Yellowstone River, thence to the Boulder River, following the latter stream to its source. Two or three days were spent in studying the Archean plateau region and the mines and volcanic phenomena near Haystack Mountain. Several days were spent on the headwaters of Clarks Fork of the Yellowstone and in the neighborhood of Cooke City, examining the mining developments in the New World district and their relations to the adjoining country.

The Absaroka Range lies on the eastern side of the Yellowstone Park, extending the entire length of the park and separating that elevated region from the low, open country to the east. The western slopes of the Absarokas lie within the park limits, and for this reason, together with the fact that the geological history of these mountains is intimately connected with, and forms a part of, the geology of the park itself, their study is essential to the correct understanding of the adjacent country. In the autumn of 1885 I made my first exploration in the Absaroka Range, in order to study the Paleozoic limestones which form the escarpments of Clarks Fork Valley, coming out from beneath the great accumulation of lava. Since that time a number of trips have been made into the country and much work has been accomplished. The plan was to complete this season the geological work necessary to the completion and publication of the two atlas sheets which cover the greater part of this range. The country included within these sheets lies between parallels 44° and 45° and meridians 109° 30′ and 110°. The area covered by these two sheets is 1,706 square miles. The maps are drawn on a scale of 1:125000, the same scale as those of the Yellowstone Park. Another reason which made the survey of this region desirable was that what is generally known as the Yellowstone Park forest reservation, or so much of it as lies east of the park, is embraced within the area covered by these two atlas sheets, and there are few regions in the Rocky Mountains more rough and rugged than the broad mass of the Absarokas. The range is a difficult one to travel over, and the higher peaks are by no means easy of access. The geology presents many difficult problems, and is, in places, intricate, but the broader features are fairly uniform over the entire area. This uniformity renders it possible to cover considerable ground in one season, so that, with what had been done in previous years, I was able to complete the work by the third week of September with sufficient detail for the maps.

From an economic point of view the Absaroka Range is of great importance to the Yellowstone Park. A vast amount of moisture in the form of snow is precipitated over the western side of the range, and numerous broad streams pour large volumes of water into the park and thence out upon a fertile plain of the Lower Yellowstone Valley. The eastern side of the range receives far less moisture. Many of its mountain slopes are barren of timber, but afford excellent grazing for cattle and horses. One object I had in view was to outline the timber and grazing lands and to examine the mineral developments found within the reservation. Two areas were visited where mining developments had been prosecuted with results sufficient to warrant a further exploration of the region. In one district, situated on Sulphur, Copper, and Galena creeks, tributaries of Sunlight Creek, a number of mining claims have been located in each canyon, and copper, lead, and silver ores extracted, but on none of these so-called "mines" had any extended shafts or tunnels been run. This locality is situated high up on the central portion of the mountains and is not easily accessible to railway transportation. The other locality is situated near the headwaters of the Shoshone River. More work has been done here, and some of the shafts and tunnels along lines of ore deposit are more extended. This latter locality is still farther removed from any line of railway communication. On Crandall Creek, in the northern part of the range, occur several exposures of white marble, which have been located as mineral lands by prospectors, and some quarrying has been done by way of testing the quality of the rock.

The last ten days of September were given to reviewing certain geological questions in the park, and the party disbanded at Bozeman early in October.

OFFICE WORK.

After returning to Washington, at the close of the field season, considerable time was occupied in recording and placing in permanent form for future use the observations and results gathered during the previous summer. Thin sections of the more important igneous rocks had been prepared for study. The somewhat meager paleontologic material has been correlated and compared with similar collections obtained from the park, and all the collections have been placed in the hands of specialists for careful study and investigation. Mr. T. A. Jaggar has transmitted his notes made in the field, together with a fine set of photographic negatives illustrating the geology of the region. These latter are exceptionally fine, and much credit is due to him for his painstaking work, often done under adverse circumstances.

During the winter and spring the greater part of the time has been occupied in the preparation of the maps and text for the folio atlas of the park and in work on the final monograph upon the geology of that interesting region.

Very respectfully,

ARNOLD HAGUE,
Geologist.

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

REPORT OF MR. WALTER H. WEED.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit herewith the following report of field and office work conducted under my charge for the year ending this day.

The field work consisted of the mapping of the areal geology of 1,700 square miles in Meagher and Fergus counties, Mont., forming the northern half of the Little Belt atlas sheet. This area embraces the mining regions of Castle Mountain and Neihart, besides several lesser camps whose prospects have made them well known. These mining regions were studied with the view of publishing reports upon the geology of the district.

In accordance with your letter of instructions, I left Washington July 1 for Bozeman, Mont., where I was joined by Prof. L. V. Pirsson, volunteer assistant. The preparation of the necessary field outfit detained me at Bozeman until July 14, when I left for the Castle Mountain mining district. I employed two men—a cook and a teamster—relying upon the wagon roads for communication, a means proving very unsatisfactory in this mountain country.

The mapping and study of the Castle Mountain district occupied the latter half of July and up to the 27th of August, when fresh supplies were obtained at the county seat—White Sulphur Springs—and the work was pushed northward to the Montana mining district, of which Neihart is the center. Professor Pirsson left the party at this point September 14, to return to his professional duties at Yale College. Heavy snow on September 20 prevented my crossing the range eastward, and on the 25th of September I returned to White Sulphur Springs, and followed the stage road past Martinsdale, Oka, Ubet, and Utica, to reach the mining town of Yogo. Several days were devoted to the geology of this camp and to the study of its gold mines, until the deep snow—2 to 4 feet on the mountains—forced me to discontinue work and return to Bozeman. Reaching that city October 12, I stored all Government property, arranged for the pasturage of stock during the winter, and started for Washington on the 14th.

In accordance with your instructions, I left Washington October 20 for Chicago, where I assisted in the packing and removal of the Survey's exhibit at the World's Fair. Returning to Washington early in November, I have since been engaged in office work.

The publication of the Livingston atlas sheet, embodying the results of field work for 1890–'91, has been successfully accomplished. The report upon the Castle mining district is nearly ready for the printer. Professor Pirsson has kindly devoted his time to a study of the eruptive rocks of this region, and will join with me in the preparation and authorship of the report.

On February 20 I proceeded, under orders from you, to Boston, Mass., to consult with Dr. J. E. Wolff, in reference to a report upon the Crazy Mountains of Montana, and to study his collections from that place. I returned February 26, and have since been working partly on this report.

The preparation and study of Yellowstone Park material has occupied a considerable portion of my time during April, May, and June. I am happy to be able to report that the part of this work under my charge is rapidly nearing completion.

The report upon the Neihart mining region can not be finished until further field work has enabled me to complete its survey.

Very respectfully,

Walter H. Weed,
Geologist.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF PROF. ROBERT T. HILL.

U. S. Geological Survey,
Washington, D. C., June 30, 1894.

Sir: I beg to submit the following report for the past fiscal year.

In July I was detailed to assist Mr. G. K. Gilbert, and accompanied him to the field in Colorado, where we were engaged in mapping the areal geology of the Pueblo sheet, as set forth in his report. In September I returned to Washington and resumed the amplification and study of my notes on the Texas region. The results of my labors since that time have been practically as follows:

(1) The revision of my check-list of the invertebrate faunas of the Cretaceous formations of Texas, the manuscript of which is now completed.

(2) The preparation of a large map of Arkansas, Indian Territory, and Texas, adjacent to the medial portion of Red River, showing the peculiar transition of the southern wooded coastal plain into the Texas Cretaceous prairie region and their relations to the southern marginal region of the Ouachita Mountains of the Indian Territory. The geology illustrated upon this map serves as a practical base for future expansion and development throughout the Texas region. A reduced copy of this map, together with a brief descriptive text, was published by the Geological Society of America.[1]

(3) A comparative study was also made from my notes of the variations in the sections along the line of strike between Red River and the Rio Grande with a detailed comparison of the Austin and Denison localities, together with a more minute and accurate definition of the Washita division of the Comanche series.

(4) At various intervals I have devoted my time to the preparation of the Fort Worth, Weatherford, Dallas, and Temple sheets of Texas, and have practically completed them for the engraver. These maps are intended to illustrate the geologic conditions of the occurrence of artesian water in this region, and their preparation required much time. I have also endeavored to devise a practical method of mapping the artesian-well area, so that the simple principles of the availability of such wells may be easily read upon the maps.

(5) During the last two months of the fiscal year I have renewed my studies of the notes previously made upon the relation of the Llano Estacado of Texas to the coastal formations of the coastal incline, and am making a special study of the central denuded region of Texas which lies between the Llano Estacado and the Cretaceous prairies of the east.

Very respectfully, yours,

ROBERT T. HILL,
Executive Officer.

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

REPORT OF MR. J. S. DILLER.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of field and office work done under my charge during the fiscal year ending to-day.

FIELD WORK.

The plan of the season's field work contemplated four ends to be accomplished: (1) The completion of the Indian Valley special sheet; (2) the subdivision of the original Tuscan formation of the Lassen

[1] Geology of Parts of Texas, Indian Territory, and Arkansas adjacent to Red River. Bull. Geol. Soc. Amer., Vol. V, pp. 297-338, pls. 12, 13.

Peak district into Tuscan and Ione formations, mapping them separately and thus completing the Lassen Peak sheet; (3) the determination of the areal distribution and faunal relation of the Chico, Horsetown, and Knoxville beds about the northern end of the Sacramento Valley; and (4) a reconnaissance of the region covered by the adjoining portions of the Red Bluff and Shasta sheets. All the work laid out was completed.

July 7 I arrived at Oroville, Cal., where I was met by Mr. James Storrs with a small field outfit. We crossed the Sierra Nevada, working by the way, to Greenville in Indian Valley. Greenville is a mining center of importance and was made the center of operations for the completion of the Indian Valley sheet. Fifty square miles were surveyed in detail on the scale of 1 mile to 1 inch, and the map was completed on July 31. At this time the party was joined by Mr. T. W. Stanton, a paleontologist of the Survey, to aid in the collection of fossils and the determination of geological horizons distinguished thereby. Important new localities of fossils were discovered in Mount Keddie and near Genesee, and knowledge of the areal distribution of the Carboniferous was greatly extended.

The Lassen Peak sheet, whose area lies chiefly in Shasta County, Cal., had been previously completed, excepting the subdivision of the Tuscan formation, the importance of which was not fully perceived until the survey of the adjacent region was well under way. After leaving Greenville the party studied the southern and western portions of the Lassen Peak district, covering in detail an area of 850 square miles, and outlining the Ione formation, which was contemporaneous in origin with the auriferous gravels upon the slopes of the Sierra Nevada. While carrying on this portion of the field work I specially studied the auriferous gravels in the adjacent portion of the area of the Honey Lake sheet, where they once covered an area of nearly 50 square miles.

Having completed the Lassen Peak sheet, I proceeded southward from Reading, along the western border of the Sacramento Valley, as far as Paskenta, being accompanied by Mr. Stanton and Mr. Storrs, making extensive collections of fossils, and clearly demonstrating the faunal and stratigraphic relations of the Knoxville, Horsetown, and Chico beds, which form the Shasta-Chico series of the Cretaceous system on the Pacific Coast.

Before returning to Washington, in the early part of November, Mr. Stanton and I spent some time collecting fossils near Kennett, in Shasta County, and Mr. Storrs was sent with an outfit to make a collecting reconnaissance for a month farther north in Shasta and Siskiyou counties. He collected six boxes of fossils, and they proved to be of great importance. They came from the Juratrias, Carboniferous, and Devonian systems.

OFFICE WORK.

On returning to Washington, I at once directed my attention to the complete revision and the extension of my paper entitled "The Revolution in the Topography of the Pacific Coast since the Auriferous Gravel Period." An abstract of this paper, containing an account of the origin of the auriferous gravels, was published in the Journal of Geology for January and February, 1894.

The results of our studies on the Shasta-Chico series of the Cretaceous system of strata on the Pacific Coast were incorporated by Mr. Stanton and myself in a paper read at the Boston meeting of the Geological Society of America and published in its proceedings.

The large number of animal fossils collected during the field season were studied, chiefly by Mr. Stanton and Mr. Schuchert. The plants obtained from the Triassic beds, as well as those from the Horsetown and Ione formations, were studied by Professor Ward and Professor Fontaine.

Among the fossils referred to Mr. Schuchert for determination he discovered a number of Devonian age, and has clearly established for the first time the occurrence of rocks of that great system on our Pacific Coast. This discovery was described in a paper by Mr. Schuchert and myself, published in the American Journal of Science for January, 1894.

The field work on the Lassen Peak sheet having been completed, it was prepared for final publication. The preliminary edition of the map was revised, and the text, especially the part referring to the cinder cone, was much enlarged.

In connection with the work of the petrographic laboratory, specimens are frequently sent to me for determination. Among those determined may be mentioned only the most important. A series of sands were examined for Professor Ward, and a number of fragments of aboriginal implements for Mr. Holmes and Mr. McGee.

During the year much progress has been made in the preparation of the sets of the Educational Series of Rocks and of the bulletin to accompany them, for distribution to the educational institutions selected to receive them. Six rocks have been added to the series: brick clay from Washington, D. C., residuary clay from the decomposition of limestone from Virginia, chalk from Texas, diabase from New Haven, Conn., aporhyolite from South Mountain, Pa., and chiastolite-schist from the Sierra Nevada of California. The bulletin now in course of preparation is well advanced, and with the assistance of Prof. G. H. Williams, Prof. J. P. Iddings, Mr. Whitman Cross, Prof. J. E. Wolff, Prof. W. S. Bayley, Mr. Waldemar Lindgren, and Mr. Walter H. Weed, all of whom are describing rocks in the collection, it is hoped that it may be ready for publication before the close of next year.

In the petrographic laboratory Mr. E. G. Paul and Mr. F. C. Ohm have been employed throughout the year. In January the demand for thin sections of rocks for study was so great that it was found necessary to employ temporary help. Mr. W. S. Robbins has since that time been engaged in the laboratory, and, like both Mr. Paul and Mr. Ohm, by his faithful and skillful work has proved himself a very valuable assistant.

The work completed during the year is as follows:

Thin sections made	3,189
Specimens cut	570
Saw-cuts made	700
Faces polished	508

Some of the thin sections, as well as some of the specimens cut, were especially large. Mr. Paul has had immediate supervision of the laboratory, doing much of the work himself. During July, August, September, and October, 1893, almost all of his time was occupied in working for Mr. Willis, editing and proof-reading maps, but since that time his afternoons have been given wholly to laboratory work.

Very respectfully, your obedient servant,

J. S. DILLER,
Geologist.

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

REPORT OF MR. WALDEMAR LINDGREN.

U. S. GEOLOGICAL SURVEY,
Nevada City, Cal., June 30, 1894.

SIR: The entire fiscal year 1893–'94 has been spent in field work. Arriving in California on July 6, 1893, I at once proceeded to complete the geological mapping of Truckee atlas sheet, of which about one-third remained unfinished since the summer of 1891. This work was finished by September 15. The Truckee sheet, embracing the summit and part of the eastern and western slopes of the Sierra Nevada, where crossed by the Central Pacific Railroad, offers an excellent field for the study and elucidation of many of the geological problems connected with the structure and history of that mountain range. Much information was obtained relative to the origin and manner of eruption of the enormous lava flows which cover a large part of the western slope, and below which extensive auriferous gravel deposits are often found. Important conclusions were also reached regarding the configuration of the mountain range during Tertiary time, and some information was obtained as to the time and character of the latest uplift, by which the present topography was established. A complete analysis of this latter problem can be expected only after the study of the adjoining sheets is completed Lake Tahce, a part of which is embraced by this sheet, was carefully examined in order to ascertain its origin and history. These results will be set forth in a special paper now in preparation.

On September 20 I began the detailed examination of the geology of the important gold-mining districts of Nevada City and Grass Valley. The basis for the geological survey was furnished by three special sheets, prepared in 1891 by the topographic branch of the Survey, and named, respectively, the Banner Hill, Nevada City, and Grass Valley. The scale is 1:14400, and each sheet comprises about 13 square miles. On each sheet a great number of mines are located. The plan included the study of the underground and surface geology, especially in relation to the auriferous deposits, the character and origin of which should be the subject of detailed research. The field work is now finished, each sheet having taken, on the average, three months for its completion. A large amount of laboratory and office work still remains to be done before the report can be completed, and the conclusions in regard to the genesis of the auriferous veins can therefore not yet be indicated. The geology is complicated, the larger area being occupied by igneous rocks of extremely variable texture and composition; in these are embedded smaller masses of sedimentary rocks, in which thus far no fossils have been found. The sequence and character of the rocks have been determined, and the mineral deposits classified and referred to the several genetic types established.

In September, 1893, I published, with your consent, a paper in the American Journal of Science, describing a new and rare type of the auriferous veins, occurring at Meadow Lake, California.

In March, 1894, a few days were devoted to the examination of an interesting occurrence of a Jurassic conglomerate, found in Placer County, and a paper describing the occurrence has been prepared.

Very respectfully,

W. LINDGREN,
Assistant Geologist.

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

REPORT OF MR. H. W. TURNER.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: In accordance with your instructions I left Washington for California on July 1, 1893, to survey the areal geology of the Downieville atlas sheet. At San Francisco I was joined by Mr. T. W. Stanton, paleontologist, who was detailed by the geologist in charge to assist in the search for fossils. On July 17 we joined the camp party at Colfax, and proceeded thence to the area of the Downieville sheet. While at Colfax, Mr. Stanton collected shells from the Mariposa shales, and in the Downieville area he made numerous collections. Some of these were of special importance, as they served to correct errors of correlation which had been made by earlier investigators. Mr. Stanton left my party on August 28 to join Mr. Diller. Three boxes of fossil leaves were collected from the Mohawk Lake beds and shipped to the National Museum.

The field work on the Downieville sheet was nearly completed by November 1. On account of the complexity of the region—a variety of old igneous rocks being mingled with the sedimentary series and the whole much metamorphosed—the field work was unusually difficult. Microscopic examination was necessary to determine the nature of some of these rocks, and this examination was made during the past winter. A few weeks' revision work will be necessary during the coming season to complete the Downieville sheet.

The first half of November was spent on the geology of the south portion of the Bidwell Bar sheet. On November 14 my party disbanded at Oroville and I returned to San Francisco.

In the central Sierra Nevada the Auriferous slate series and the associated volcanic rocks form a belt from 25 to 30 miles wide on the western slope of the range, and the series is largely replaced by granites a little to the south of latitude 37° 30′. To determine more exactly the manner in which the slate series ends, and the relation of the granite to the series, a trip was made into Madera and Mariposa counties in December, 1893. Mr. W. T. Turner accompanied me as assistant.

At Bear Valley, in Mariposa County, a collection of fossils was made from the Mariposa slates, and shipped to the National Museum. Some specimens of mariposite were collected from the Josephine mine on the Mother lode. As this micaceous mineral has never been analyzed, the material was turned over to the chemical division.

I returned to San Francisco from Mariposa County on December 25, 1893, and left for Washington on January 10, 1894.

In Washington I was employed in the examination of thin sections of rocks with the microscope, and with other office work, till May 8, when by your orders I again returned to the San Francisco suboffice. On June 10 I took the field in Butte County, continuing areal work on the Bidwell Bar sheet.

Very respectfully, your obedient servant,

H. W. TURNER,
Geologist.

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

REPORT OF PROF. ANDREW C. LAWSON.

UNIVERSITY OF CALIFORNIA,
Berkeley, Cal., June 30, 1894.

SIR: I have the honor to report as follows upon the progress of the geological investigation of the region around the Bay of San Francisco during the past fiscal year.

The field work has been prosecuted chiefly in the university vacation, but in part, also, at irregular intervals throughout the year. It has been carried on partly by aid of a small allotment placed at my disposal by the Director of the Survey and partly by volunteer and unremunerated services. The region under examination consists of the quarter-square degree, between latitude 37° 30′ and 38° and longitude 122° and 122° 30′, comprising portions of the counties of San Francisco, San Mateo, Marin, Alameda, and Contra Costa. The geological mapping of the different formations has proceeded as the results of the topographic survey became available. A portion of the area having been already mapped by the U. S. Coast and Geodetic Survey, the published sheets of the latter, on a scale of 1:40000, were used in the absence of the topographic atlas sheets of the Geological Survey. Early in the year the San Mateo and Millbrae atlas sheets became available in the form of photographic prints, on a scale of 2 inches to the mile, and these were used with eminently satisfactory results. With these maps in hand, two months of continuous field work were spent in tracing out the boundaries of the various formations found in this field. In this work I was efficiently assisted by Mr. Charles Palache. During the same period Mr. Leslie Ransome was entrusted with some mapping in Alameda and Contra Costa counties, and was engaged about one month. Both assistants were at the time graduate students in geology at the University of California, and their employment, while affording them the necessary training for geological investigation, was found to be very advantageous to the progress of the field work. After the opening of the academic year, field work was carried on only by means of occasional short excursions.

The results of the year's work, so far as mapping of formations is concerned, are that the field work on the Millbrae, San Mateo, and San Bruno atlas sheets, all on a scale of 2 inches to the mile, is completed. The work done on the San Francisco atlas sheet (scale 1 mile to 1 inch), added to that of the previous year, nearly completes the mapping of that sheet, but, as the topography is not yet entirely mapped, it has been impossible to finish the geological mapping. It will require about two weeks of continuous work in the field to complete it. Some work was also done on the Walnut Creek sheet.

The mapping of the geological formations is, of course, only a part of the investigation of the field, and is largely preliminary to the discussion of their various relations. The only portion of the field which has been as yet sufficiently studied to permit of a discussion of its geology is the San Francisco peninsula, from latitude 37° 30′ northward. A paper giving a sketch of the geology of the peninsula is herewith submitted for publication.

Besides this local work in the vicinity of the Bay of San Francisco, some inquiry has been made into the distribution, volume, petrography, and structure of the bituminous shale of the Monterey series by means of occasional excursions through the coast ranges, where the formation is well developed. This formation, being the source of the so-called "bituminous rock," asphaltum, and probably of most of the oil of California, is one of the most important economic features of the coast ranges, and demands special and extended investigation. From a purely scientific point of view it is one of the most unique and remarkable formations with which we have to deal.

In addition to the progress of the work above outlined as being under the auspices of the U. S. Geological Survey and partly aided by it, other investigations in the field have been made under the auspices of the University of California, and results arrived at which will be of prime importance in the final discussion of the geology. Of these may be cited the studies on "The Soda Rhyolite north of Berkeley,"[1] "The Lherzolite Serpentine and Associated Rocks of the Potrero, San Francisco,"[2] and "A New Soda-Amphibole from the Vicinity of Berkeley,"[2] by Mr. Palache; the studies on "The Eruptive Rocks of Point Bonita,"[3] and the "Geology of Angel Island,"[4] by Mr. Ransome; and "The Post-Pliocene Diastrophism of the Coast of Southern California,"[5] by myself. These various special studies and others now under way are very necessary adjuncts of the more general work of the Survey, particularly in this new field, where little or no previous detailed work has been done. As the region adjacent to the Bay of San Francisco appears to be representative of a large portion of the coast ranges of California, these special studies at the University of California, taken with the geological mapping and general investigations of the Survey, will, it is hoped, yield in the near future the material for a monograph of a typical section of the coast ranges.

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

ANDREW C. LAWSON.

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

---

[1] Bull. Dept. Geol., Univ. California, Vol. I, No. 2.
[2] In press.
[3] Bull. Dept. Geol., Univ. California, Vol. I, No. 4.
[4] Ready for press.
[5] Bull. Dept. Geol., Univ. California, Vol. I, No. 3.

REPORT OF PROF. T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
Chicago, Ill., June 30, 1894.

SIR: I have the honor to submit the following statement of my work for the Survey during the year ending June 30, 1894.

Assistant Geologist Leverett began field work at the opening of the fiscal year in southwestern New York. His studies embraced all phases of the glacial formations, but he gave especial attention to tracing out the several terminal moraines of the region, and to the determination of relative ages and mutual relationships and connections. He continued this work until about the middle of August, after which he resumed work at Wheeling, W. Va. He took up the study of the glacio-fluvial deposits and their associated formations, and endeavored to trace out their connection with and relationship to the glacial series lying farther north and west, upon whose study he had been previously engaged. He continued this study, working northward until November 1, when he resumed the morainic investigation in southwestern New York. Upon this work he continued until the close of the month, having at that time extended his studies as far eastward as the Genessee River, and covered practically all of the territory west of that river and south of Lake Ontario. On the 1st of December he returned from the field, and until May 1 was engaged in office work, chiefly the further study and writing up of his results. A portion of this was done jointly with myself. This work was slightly interrupted in April by a visit to points in northeastern Illinois to secure further data relative to the moraines of Kane County and the erosion of the Desplaines Valley.

After May 1 Mr. Leverett's work consisted largely of a study of the drift sheets of southeastern Iowa with a view to determining the mutual distribution and relations of the drifts of the Illinois and Iowa tracts, which were produced by separate glacial lobes. In connection with this he studied also the relation of the loess to the drift sheets, the further changes of drainage, and the conditions that controlled the several deposits, together with many minor questions.

The work of Mr. I. M. Buell in connection with the Survey has chiefly consisted in recasting and further elaborating, in connection with the writer, a report upon the bowlder trains of southeastern Wisconsin and the formations associated with them. In connection with this a few brief revisits for special purposes were made during the summer and autumn of 1893.

Prof. J. A. Udden was employed under a special arrangement, with scarcely more than nominal compensation, to undertake the investigation of the hypothesis that the Mississippi formerly departed from its present channel at a point above Rock Island and flowed southeasterly to the great bend of the Illinois River, near Hennepin, and there occupied a broad, deeply buried valley, which was many years ago discovered by yourself. This investigation was pursued during the summer of 1893, occupying the larger portion of the months of July and August and a part of September. It was supplemented by investigations undertaken in June, 1894. In the course of this study a wide belt between the present location of the Mississippi and the bend of the Illinois was traversed and all available data were collected. The study was also extended west of the Mississippi to determine whether or not a buried valley lay in that quarter.

The work of the writer, so far as in the employ of the Survey, has consisted of the direction of the field work in progress and of joint studies with Mr. Leverett and Mr. Buell of the formations above mentioned, which had previously been studied in part by the writer, the endeavor being to combine data and prepare for publication the results of our collaboration.

Very respectfully,

T. C. CHAMBERLIN,
Geologist.

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

REPORT OF MR. DAVID WHITE.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I beg to submit the following report of the work in my charge during the fiscal year ending June 30, 1894.

FIELD WORK.

Nearly five months of the current year were devoted to field work. I was occupied from the 1st of July until early in October as assistant to Mr. Campbell in regular areal work on the Dublin and Pocahontas sheets, in Virginia and West Virginia. Considerable mapping was also done of the contiguous portions of the adjacent areas on the south and east. The account of our stratigraphic operations will be found in Mr. Campbell's administrative report.

Small collections of invertebrate fossils were made from the Silurian and Devonian of several localities in the Wytheville, Hillsville, and Christiansburg sheets, and from the Lower Carboniferous and Devonian in the Pocahontas and Dublin sheets.

The most important paleontologic work, however, was that begun for the purpose of establishing a paleobotanic section, as nearly as possible continuous, through the Lower Carboniferous and "Conglomerate series," in order (1) to furnish a standard for the comparison of other local floras in the Eocarboniferous sections of this portion of the Appalachian region, and (2) to procure data for a broader correlation with certain fixed stages in the Pennsylvania type sections. With this end in view, plant remains were gathered from the Pocono formation near Wytheville, Pulaski, and Blacksburg, in Virginia, and from the calcareous shales of the Lower Carboniferous on the Bluestone and New rivers. Also obscure and fragmentary remains were found in the Devonian and Lower Carboniferous in other portions of the sheets. More comprehensive collections were made at various horizons in what is commonly known as the "Conglomerate series" on Great Flat Top Mountain and between the Quinnimont and Nuttall coals along the New River. These collections were often necessarily quite incomplete, and therefore lacking full paleontologic value, because the pressure of other work left little time for the discovery and exploitation of localities. Moreover, the scarcity of plant remains natural to a series so largely arenaceous is responsible for several gaps in the paleontologic sequence. Yet, enough material was gathered to not only fix within fairly narrow limits several plant-bearing horizons in other portions of the same regions and in Georgia, Alabama, Arkansas, and Tennessee, but also to throw much new light on the history of the Carboniferous flora so far as it has been described in the northern coal basins.

I was engaged during October, as a member of Mr. Keith's party, in areal work on the Briceville sheet. Small collections were made from the coals mined at Briceville, Caryville, Pioneer, and Big Creek Gap, in Tennessee, and from a high coal near the top of the mountain at Caryville.

Two short intervals were devoted to field investigations in Pennsylvania, in connection with special office work at Pittston. The first, a week in May, was spent in studying the stratigraphy of the Forkston coal in the Mehoopany basin in Wyoming County, and of the Bernice coals in the Loyal Sock area in Sullivan County. The results, including the paleontologic determination of the age of the coal, were fairly satisfactory.

From June 11 to June 20 I was engaged in procuring fossils from the various coals in the "Pottsville Conglomerate" series of the southern Anthracite basin, the floras of this series in Pennsylvania being hitherto almost unknown except at a single stage at Coxton. Material in small quantities was hurriedly gathered from nearly every workable coal of that series in the Southern Anthracite field. Fragmentary collections were fortunately made from several shale partings in the type section of the series at Pottsville Gap in the Sharp Mountain. The fossils from this section are most important, and will prove indispensable in any attempt at paleontologic correlation between the coals of the southern Appalachian areas and the Pennsylvania series.

OFFICE WORK.

From the time of my return from Tennessee to Washington, early in November, until the 2d of March I was occupied in arranging and studying various collections, including those made during the preceding field season. I reported preliminarily on the latter at a meeting of the Geological Society of Washington on the 28th of February. The reports on the floras of the coals of Washington County, Ark., and of the Lower Coal Measures in Missouri have progressed nearly to completion. Work on this manuscript is suspended until the illustrations needed to accompany it are prepared. I continued from March 3 to June 11, with the exception of one week, the special work of review, identification, etc., in the Lacoe collection at Pittston, preparatory to its removal to the U. S. National Museum. One hundred and twelve boxes of fossils were shipped to Washington. On June 20 I returned to Washington, D. C., since which date I have been occupied with routine work.

In conclusion, I desire to make acknowledgment of the cordial assistance given by Mr. Campbell in Virginia and West Virginia, and of my indebtedness for valuable counsel to the chief paleontologist, to Professor Ward, and to Mr. R. D. Lacoe, of Pittston, Pa.

Very respectfully, your obedient servant,

DAVID WHITE,
Assistant Paleontologist.

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

REPORT OF MR. T. W. STANTON.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report on work done during the year ending to-day.

FIELD WORK.

At the beginning of the fiscal year I left Washington in company with Messrs. J. S. Diller and H. W. Turner for field work with their parties in California. Pending the organization of Mr. Turner's party, a few days were spent in the neighborhood of Martinez and Benicia, Cal., examining and collecting from the Cretaceous strata there, and some time was also given to the study of the important collections in the University of California, at Berkeley, and in the California State Mining Bureau, at San Francisco.

On July 17 I left San Francisco with Mr. Turner for his field of work on the Downieville and Bidwell Bar sheets, in the northern Sierra Nevada, spending one day en route in examining the Jurassic beds near Colfax.

With the exception of five days in the latter part of July and the beginning of August, when I visited Genesee Valley and Taylorville for the purpose of reviewing the well-known Mesozoic section there, the time from July 21 to August 28 was spent with Mr. Turner's party in the area above mentioned. Careful search was made for fossils in the metamorphosed rocks of that region, and, though the search was rather unsuccessful, enough characteristic fossils were found at a few localities to determine the horizon of the beds containing them, and some aid was thus given in the work of mapping.

August 29 I joined Mr. Diller's party in Genesee Valley, and after spending two days in collecting from some doubtful horizons near there, we proceeded to the Sacramento Valley, for work on the Cretaceous and earlier Mesozoic deposits, stopping en route to examine several Carboniferous and Triassic localities.

Beginning at Butte Creek and going northward along the east side of the valley as far as the great bend of Pit River, then returning and crossing the northern end of the valley by way of Redding, thence going down the west side to Paskenta, under the guidance of Mr. J. S. Diller, who was already familiar with the details of the geology at various localities, I had an exceptionally favorable opportunity for a study of the entire Cretaceous series from the Chico down through the Horsetown and Knoxville beds. Important collections were made from all these horizons and also from the Jurassic and Triassic of the Pit River region, both the other members of the party—Mr. Diller and Mr. James Storrs—taking an active part in the work of collecting. This investigation resulted in demonstrating that the entire Cretaceous series of that region is the product of continuous sedimentation. The evidence for this conclusion is detailed in a joint paper by Mr. Diller and myself on "The Shasta-Chico Series" (Bull. Geol. Soc. of America, Vol. V, pp. 435–464).

This study occupied the time until October 20, when the field season was closed by a visit to a fossiliferous locality (since determined to be Devonian) near Kennet, on the Sacramento.

On the return journey a stop of about two weeks was made in Chicago, where the Geological Survey's exhibit of fossils at the World's Columbian Exposition was packed and prepared for shipment to Washington, which place I reached November 16.

OFFICE WORK.

The time since that date has been devoted to laboratory and office work, which consisted mainly of the preparation and study of the collections made during the field season. All of the Cretaceous fossils were examined in the preparation of the paper on the "Shasta-Chico Series," and the fauna of the Knoxville beds, being mostly new, was taken up for detailed study and description. The first draft of this paper is now written and will be ready to offer for publication as soon as the necessary drawings are finished.

Considerable time has been given to the examination of fossils for the geologists of the Survey and for others not connected with the Survey. Twenty-one such examinations, usually of small collections, have been made and reported on during the year. This kind of work has precedence over all the more systematic studies that are in progress.

In March about a week was devoted to assisting in the installation of the Survey's World's Fair exhibit of invertebrate fossils, which is now displayed in the National Museum.

Mr. T. E. Williard was employed as a laboratory assistant for two months, beginning January 15, and his work for one-half of this time was under my direction.

Besides the joint paper already mentioned, my paper on "The Colorado Formation and its Invertebrate Fauna" (Bull. 106, U. S. Geol. Survey) was published in March, 1894.

Very respectfully,

T. W. STANTON,
Assistant Paleontologist.

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

REPORT OF DR. W. H. DALL.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report on operations in Cenozoic paleontology during the fiscal year ending June 30, 1894.

My only official assistant during the year has been Mr. Frank Burns, who has faithfully attended to the duties assigned him, chiefly comprising the cleaning, assorting, and arranging of specimens on hand and the selection of specimens to be sent out to correspondents from among the named duplicates.

I have gratefully to acknowledge the continued help of Mr. Joseph Willcox, Mr. T. H. Aldrich, Mr. Charles W. Johnson, and Mr. H. A. Pilsbry, who, as correspondents and experts, have assisted in many ways connected with the working up of our Neocene fauna, both officially and unofficially. The Wagner Free Institute of Science, Philadelphia, and the U. S. National Museum, under the direction of the Smithsonian Institution, have continued to extend facilities of various kinds without which it would have been difficult to carry on the work.

ROUTINE WORK

The routine work has consisted as usual, largely in cleaning, assorting, classifying, recording, naming, labeling, cataloguing, and arranging in order for easy reference and study the fossils of Cenozoic age and their later related forms

Next to this in amount of labor comes reporting upon collections made by members of the Survey in order to determine the age of the beds in which they are found. Similar reports are frequently requested by members of State surveys who have not the means for identification of their material on account of lack of access to large collections and libraries. Private students of geology frequently ask for similar assistance for the same reasons. Such requests have been complied with whenever possible, the writer regarding such work, when not conflicting with official duties, as one of the most useful and proper functions of a national survey. In the year 1892–'93 there were 336 communications from 96 different people, the replies to which involved the writing of over 600 pages of manuscript, all of which was done by the writer personally. In the year 1893–'94 the number of communications was 450 from 150 people, and the written responses, all of which were made by myself personally, covered some 920 pages of letter sheets.

No record of the number of specimens identified could be kept, for want of clerical assistance; a large number, however, have been reported on for Messrs. G. H. Eldridge, N. H. Darton, R. T. Hill, Whitman Cross, and others of the Survey, and among outsiders especially for Prof. A. C. Lawson, State University of California, Berkeley, Cal.; Dr. C. F. Newcombe, Provincial Museum, Victoria, British Columbia; Rev. H. Loomis, Yokohama, Japan; Prof. E. A. Smith, State geologist of Alabama; Prof. E. T. Dumble, State survey of Texas; Prof. Jno. C. Branner, State geologist of Arkansas; Lewis Woolman and Joseph Willcox, of Philadelphia, as well as occasional specimens for many others.

The reprint of Conrad's "Medial Tertiary Fossils," undertaken by the Wagner Institute and edited by the writer, was successfully carried out, and places once more at the disposal of students one of the rarest and most important works on American Tertiary fossils.

Work has been continued on the final part of the "Tertiary Fossils of Florida" in the intervals of official work of a more pressing kind, and it is hoped to conclude it during the coming year.

Collections of specimens from the French Eocene and Miocene, important for comparison with our own fossils of similar age, were received, in exchange for American material, from several foreign correspondents. The total number of species amounts to over 1,000, represented by nearly four times as many specimens.

No current routine work is in arrears. The only arrears are in the administration upon material which has accumulated and which is being put into shape for use as fast as our limited time and opportunity will admit.

FIELD WORK.

The funds at my disposal admitted only of a very limited amount of field work. It was decided to expend this chiefly in cooperation with Mr. J. Stanley-Brown in making a reconnaissance of the geology of southwestern Georgia and western Florida along the Flint and Apalachicola rivers. Here some discrepancy between various accounts of the succession of the Tertiary beds left a doubt over much of the Florida work which it was most important to dispel. This was accomplished in October and November, 1893, the results being very satisfactory and thoroughly clearing up previous questions as to the succession of the various Tertiary horizons hitherto observed in this region. A brief synopsis of the results was, by permission of the Director, printed in the Bulletin of the Geological Society of America, Vol. V, pp. 147–170, February, 1894.

Further explorations of the same sort along the more western rivers parallel with the Apalachicola will doubtless place the geology of the coast Tertiary of the eastern Gulf States in a firm position. We have had in all this work the cordial cooperation and advice of Dr. E. A. Smith, State geologist of Alabama, to whom we are much indebted. We were also much indebted to Maj. T. B. Brooks and Mr. R. A. Lytle, of Bainbridge, Ga., for important aid in arranging the details of the exploration.

An understanding has been established with Prof. J. A. Holmes, State geologist of North Carolina, for cooperation in the study of the Tertiary of that State, which it is believed will be mutually helpful and tend to the complete exploration of the very rich deposits of fossils for which North Carolina is so noted.

I remain, very respectfully,

WM. H. DALL,
Paleontologist.

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

REPORT OF PROF. O. C. MARSH.

U. S. GEOLOGICAL SURVEY,
New Haven, Conn., June 30, 1894.

SIR: I have the honor to submit the following report of the work in vertebrate paleontology during the past year.

In compliance with your letter of general instructions, I have continued the work of collecting vertebrate fossils and investigating those of special importance to science. The former work has necessarily been much restricted during the year, but the work of investigation has gone on systematically and with good success.

The field work has been confined to the Tertiary formation, especially the Miocene deposits along the eastern base of the Rocky Mountains. The main object in view has been to settle two questions in stratigraphic geology of much scientific interest. One of these questions was the relation of certain deposits in the Miocene of the Atlantic Coast to strata in the Rocky Mountain region found to contain fossils somewhat similar. As a result, a definite horizon common to the two regions has for the first time been established. The Miocene strata in New Jersey, which I have carefully explored and named the Ammodon beds, are shown to have their near equivalent in fresh-water lake deposits of the West, the genus Elotherium and its allies occurring in the two regions in essentially the same horizon.

Another question of still greater importance has been settled by the investigation of the past year. In 1871, and again in 1873, I explored the Miocene deposits along the valley of the John Day River in Oregon. The strata were found to be nearly a mile in thickness, and deposited in a single lake basin, which I named the John Day basin, from the river that now drains it. The upper portion of these Miocene deposits was found to represent a distinct horizon, which I named the Miohippus beds, from the most characteristic equine genus discovered in it. Subsequent researches brought to light many other interesting fossils in this horizon, which has been supposed to be represented only on the Pacific Coast.

The researches which I have conducted during the past year in the Miocene lake basins on the eastern slope of the Rocky Mountains have demonstrated that the uppermost strata contain the genus Miohippus as one of their characteristic fossils, and that other genera hitherto known only from the Oregon beds are present. The fact is thus established that the Miohippus horizon has an eastern as well as a western division, and a direct comparison between the deposits of the two regions can be made.

The importance of certain extinct animals in marking definite horizons is so great that during the past year I have continued the work of restoring those especially characteristic. The genus Coryphodon is known only from one horizon at the base of the Eocene, in this country and Europe, and the restoration of one of the largest species, which I have recently published, will prove of interest alike to geologists and paleontologists. Another restoration, that of Elotherium, from the Miocene, is worthy of notice; and a third, of Camptosaurus, one of the large Jurassic Dinosaurs, I have also made during the past year. The last animal is of special interest because it is the American representative of the Iguanodon of Europe, although an earlier type.

All the above work, although important in itself, has been kept subordinate to the early completion of the monographs in preparation. On these good progress has been made. Important discoveries made it necessary to go over the whole subject of the Sauropoda anew, but this will make the volume more complete and valuable than it would have been as first planned, and its early publication is now assured.

The following papers on vertebrate fossils and their relations to stratigraphic geology have been published by me during the past year:

Some Recent Restorations of Dinosaurs. Nature, Vol. XLVIII, pp. 437–438, London, September 7, 1893.

Restoration of Coryphodon. With two plates. Amer. Jour. of Science, Vol. XLVI, pp. 321–326, plates v, vi, New Haven, October, 1893.

Description of Miocene Mammalia. With four plates. Amer. Jour. of Science, Vol. XLVI, pp. 407–412, plates vii–x, New Haven, November, 1893.

Restoration of Camptosaurus. With plate. Amer. Jour. of Science, Vol. XLVII, pp. 245–246, plate vi, New Haven, March, 1894.

Restoration of Elotherium. With plate. Amer. Jour. of Science, Vol. XLVII, pp. 407–408, plate ix, New Haven, May, 1894.

A New Miocene Mammal. Amer. Jour. of Science, Vol. XLVII, p. 409, New Haven, May, 1894.

Footprints of Vertebrates in the Coal Measures of Kansas. With two plates. Amer. Jour. of Science, Vol. XLVIII, pp. 81–84, plates ii, iii, New Haven, July, 1894.

The Typical Ornithopoda of the American Jurassic. With four plates. Amer. Jour. of Science, Vol. XLVIII, pp. 85–90, plates iv–vii, New Haven, July, 1894.

Eastern Division of the Miohippus Beds, with notes on some of the Characteristic Fossils. Amer. Jour. of Science, Vol. XLVIII, pp. 91–94, New Haven, July, 1894.

Very respectfully,

O. C. Marsh,
Paleontologist.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF PROF. LESTER F. WARD.

U. S. Geological Survey,
Washington, D. C., June 30, 1894.

Sir: I have the honor to submit the following report of work done in paleobotany during the fiscal year.

FIELD WORK.

All the field work during the year has been in the Lower Cretaceous plant-bearing deposits of the United States. By the end of June, 1893, I had practically concluded the operations which I had planned for the study of the Potomac formation in Virginia and the States farther north. A careful review of the literature of this subject, including an important unpublished memoir by Professor Fontaine on the geology of the Potomac formation in Virginia, showed that my conclusions were in many cases at variance with those of other geologists. There also remained a considerable number of unsettled questions, and I was very desirous to secure the opinion on all of these points of some of the previous workers. As Professor Fontaine was the one who had studied the formation chiefly from the paleontological side, I felt that I could acquaint him more easily with the evidence that I had accumulated than I could any of the other geologists. Early in July, therefore, I requested him to come to Washington and cooperate with me for a short time in the study of the Potomac formation. The object was to visit as many of the critical points as possible, to reexamine them thoroughly, and to discuss all questions arising out of the facts presented.

This purpose was very fully carried out in the course of the twenty-five days' field work done by us in July. We visited all the localities of special interest in the District of Columbia, in Maryland, and in Virginia as far south as the Rappahannock. We examined with care the important exposures in the cities of Washington, Baltimore, and Fredericksburg, and those along the banks of the Severn, Potomac, and Rappahannock rivers. Our studies were especially directed to the verification of the important hypotheses advanced by the several geologists who had investigated the formation, and guided by these we were able to make many observations which would otherwise have been overlooked. I need only say here that in concluding our labors there remained no entirely unsettled question, all matters of doubt having been decided in such a manner as to insure harmony of opinion between Professor Fontaine and myself.

At irregular intervals since that date I have continued to make local observations in the same field, and by correspondence with Professor Fontaine, have been able still further to perfect our knowledge of the formation.

In my last report mention was made of a collection of cycadean trunks acquired by the National Museum from the vicinity of Hot Springs, Fall River County, S. Dak., their geological importance was referred to, and the hope was expressed that I should soon be able to visit the locality for the purpose of determining their stratigraphical position. With this object in view, early in September, 1893, I undertook an expedition to this region. I had previously arranged with the parties at Hot Springs from whom the specimens had been obtained, to guide me to the locality. I had also corresponded with Prof. W. P. Jenney, who was at the time at Deadwood, and who joined me at Hot Springs on my arrival and accompanied me on the expedition. A suitable outfit was secured and a thorough search made, which was successful in all respects. The locality is some 5 miles southwest of Minnekahta station, upon a ridge located in the area designated by Professor Newton in his report on the geology of the Black Hills as belonging to the Dakota formation. Most of the perfect specimens had been removed, but a few remained, including one very large branching one quite different from any that had been obtained before; also many fragments of great value. A fine series of these latter, as well as the large specimen referred to, were secured, and arrangements were made for their transportation to Washington.

This might have closed the expedition, but the great improbability that the cycads could have lived in the Dakota period led us to doubt the accuracy of the earlier determination of the age of these beds and to undertake an investigation of the entire series of rocks in which they occurred. Careful sections were made at different points in this series, and we were successful in finding vegetable remains other than the cycads both above and below the level at which they occur. Much silicified wood was also found at the same horizon as the cycad trunks. The character of the vegetable remains was practically conclusive as to the Lower Cretaceous age of the beds in which they were found.

Professor Jenney has recently reported to me the result of additional investigations made by him in May and June, 1894, at the same horizons as those in which we worked in September, but in different parts of the Cretaceous rim of the Black Hills, in the course of which he has fully confirmed and greatly strengthened the conclusions at which we arrived, and he has sent on the evidence in the form of considerable collections of fossil plants.

In the early part of the winter I learned that a collection of cycadean trunks had been made by Mr. Arthur Bibbins, curator of the museum of the Woman's College, at Baltimore, and in corresponding with him and with Dr. John F. Goucher, president of that college, I ascertained that the specimens were from the Iron Ore region of Maryland and therefore practically the same as the well-known trunks collected by Tyson in 1859. Through the great liberality of President Goucher I was not only permitted to examine the collection at the Woman's College, but succeeded in negotiating for the loan of the entire collection with a view to its study in connection with the specimens from South Dakota, and it is now in my hands for that purpose. I mention this under the head of field work because involved in this transaction was the further valuable privilege of accompanying Mr. Bibbins to the localities at which he had obtained the specimens. This was of the utmost importance to me in view of the differentiation which I had made of a number of distinct horizons within the Potomac formation, and for the settlement of the question as to the exact stratigraphical position which the cycadean trunks occupy. This expedition was undertaken in March, and, though several times interrupted, was so far perfected that I have been able to visit all the localities for cycads in Maryland so far as it is possible to locate them. In most cases, however, the specimens were found in the possession of the inhabitants, and it was necessary to accept their testimony as to their original position, but as Mr. Bibbins has obtained no less than thirty such specimens and learned of a considerable number of others which can not now be found, it was possible to arrive at tolerably safe conclusions as to their true horizon, and in two cases at least they were actually found in place. In this way there has been settled one of the most important and difficult questions relating to the geology of the Potomac formation.

OFFICE WORK.

No changes have occurred in the force of the office during the year, but an exchange with the United States National Museum of the services of Prof. F. H. Knowlton for those of Mr. David White, the same as that mentioned in my last report, has been made, covering the period from March 1 to June 20.

Original research.—I have devoted the greater part of my time, when not in the field, to working up the general results of my investigations into the Lower Cretaceous, and especially the Potomac formation. To the wider field of operations belongs the work on my notes from the Black Hills. A somewhat careful memoir embodying the results of that expedition was prepared on my return and published, with your permission, in the Journal of Geology (Vol. II, No. 3, Chicago, April-May, 1894, pp. 250-266). The important bearing of the fossil cycadean trunks already referred to upon the subject made it necessary to undertake an exhaustive study of the materials in hand, including the large collection borrowed from the Woman's College of Baltimore. As the leading characters of these trunks are revealed only by their internal structure, it was necessary to have sections cut in order to show this and microscopic slides prepared for its detailed study. Prof. F. H. Knowlton, being skilled in matters of internal structure, was asked to cooperate and take charge of this part of the work, which he consented to do. Progress in this has been slow, and very much still remains to be accomplished.

The literature of cycadean trunks is very extensive, dating back to 1753, and the material of this nature from the south of England, the interior of Italy, and from France and Germany has been the subject of several exhaustive papers by Buckland, Williamson, Carruthers, Capellini, Solms-Laubach, Lignier, and others, some of them quite recent. These researches have caused many changes in the nomenclature and thrown much light upon the nature of these objects. I have therefore been compelled to go carefully over these several publications, and have found it worth while to attempt a revision of the synonymy. In the case of the principal genus, Cycadeoidea, to which all the American forms thus far found seem to belong, I have published such a revision[1] and given a succinct account of the American discoveries. The revision of the other genera has been prepared, but has not yet been published.

By the 1st of February I had so far advanced with my work on the Potomac formation that I was able to begin the preparation of manuscript. It was, however, not thought best to proceed at once with the chapter of my correlation essay relating to the Lower Cretaceous. Much time had been devoted to the Potomac formation—that is, to that part of the Lower Cretaceous east of the Mississippi River—and the conclusions reached in its study were so important, especially those relating to the subdivision of the formation, that they seemed to justify the preparation for publication in advance of a somewhat condensed report upon this restricted topic, the greater part of which could be used in its proper place in the more extended report. Such a paper was begun in February and is now completed, and has been submitted for publication in the present annual report. It includes about 150 pages of typewritten manuscript, three plates illustrating the Mount

---

[1] Proc. Biol. Soc. Washington, Vol. IX, pp. 75-88, April 9, 1894.

Vernon flora, and two special, and three general, diagrammatic sections illustrative of the stratigraphy.

A large part of my time during the year has been spent in the determination of the collections made and the identification of forms not yet described with published species. This has been especially the case with the higher beds of the Potomac formation, but I have also identified a considerable number of those from the Mount Vernon clays, the three plates of the paper above described being devoted to these forms. In addition to this I have determined the plants that were collected by Professor Jenney and myself from the true Dakota formation in the Black Hills.

Quite a large collection of plants of the Older Potomac had been made from a great number of localities. These, together with the specimens collected on the Black Hills expedition from the basal portion of the Cretaceous, were sent in October to Professor Fontaine for determination and were reported upon in full by him in January.

A collection of fossil plants made by Mr. Diller's party from the Horsetown and Knoxville beds of California, belonging to the Shasta group, was sent in February to Professor Fontaine, who gave it immediate attention, and before the end of that month submitted a very satisfactory report. All of these reports have been utilized in the preparation of my paper on the Potomac formation.

As already intimated, on the departure of Mr. White for Pittston, on the 1st of March, to continue the work of preparing the Lacoe collection for shipment to Washington, Professor Knowlton resumed his studies in the Laramie and post-Laramie, the character of which has already been reported. On account of the existence of a large amount of published material from the beds on which he was engaged—in the collections at Cambridge, Columbia College, New York, and Princeton—it became necessary for him to visit those places in order to incorporate this material into his report. This he did in April, leaving Washington on the 12th and returning on the 26th. The rest of the time until Mr. White's return was devoted by him to the work in the National Museum, which is now approaching completion, 538 pages of manuscript having been prepared, consisting of critical notes and comparisons and the descriptions of new or rare species. About forty new species have been described during this period, a number of which are founded on specimens belonging to the School of Mines, Columbia College, which were kindly loaned for the purpose.

Several papers based on these and other researches of Professor Knowlton's, some of which were made during the year, have appeared. Among these are an "Annotated List of the Fossil Plants of the Bozeman, Montana, Coal Field, with Table of Distribution and Description of New Species" (Bull. U. S. Geol. Surv. No. 105, pp. 43-66, pls. v and vi); "A Review of the Fossil Flora of Alaska, with Descriptions of New Species" (Proc. U. S. Nat. Mus., Vol. XVII, pp. 207-240); abstract of the same, under the title, "Fossil Flora of Alaska" (Bull. Geol. Soc. Am., Vol. V, 1893, pp. 573–590.)

Professor Knowlton has also made a number of minor reports upon collections submitted for determination and in answer to questions arising out of paleobotany, especially on a small collection of fossil plants of California received from Mr. Waldemar Lindgren; on fossil wood found in the cycad bed near Minnekahta station, S. Dak.; on a small collection made 2 miles south of Clarkes Fork Canyon, Big Horn basin, Wyoming; and on the present status of the flora of Florissant, Colo.

Although at the time of his death Dr. Newberry had nearly completed his memoir on the "Flora of the Amboy Clays," there still remained a great amount of work to be done, largely of a clerical or editorial, but to some extent of a scientific, character. This work was intrusted to Dr. Arthur Hollick, but it was impossible for him to complete it without making use of the facilities in the department of fossil plants at the National Museum, and practically it devolved upon me to put on the finishing strokes. The manuscript was in my hands for several months and I devoted a great amount of time to the verification and correction of the literary references and to other essential details. I completed this part in November and returned the manuscript and drawings to Dr. Hollick. As a result of the intimate acquaintance thus acquired with the memoir, I recommended a complete rearrangement of the genera and species to conform to principles of modern classification. In February I was again obliged to visit New York and assist Dr. Hollick in his effort to determine what collections left by Dr. Newberry properly belonged to the Geological Survey, and while I was there we jointly revised this classification and decided upon the final form of the manuscript, which was soon after returned to Washington and at the end of March was submitted for publication as a monograph of the U. S. Geological Survey.

Work on the Compendium.—In my last report I gave an account of the commencement of a part of the work on the compendium, which I have designated as a "List of Species and Synonyms," to contain all the names known to paleobotany. The work on this list, which was done by Miss L. M. Schmidt, had progressed at the end of the last fiscal year as far as the letter S. By the end of August the regular alphabet had been disposed of, but there remained a large number of slips called "miscellaneous," which do not contain the name of any genus or species. These slips refer to objects of a vegetable nature recorded in the books under vernacular names, but often carefully described and figured. Such descriptions and figures constitute, in a large number of cases, the first mention of fossil plants which have been subsequently named and enrolled in the literature of the science. It thus frequently happens that the type figure to which it is necessary to revert in any careful study of the species is not accompanied by a systematic name, which renders such references of very great importance.

Before these miscellaneous slips could be entered in the list it was necessary to classify them on some logical principle. This work engaged my attention for a considerable period in the fall, and it was not until December that I had so far perfected it as to enable Miss Schmidt to proceed with the typewriting. She finished the entire list of species and synonyms, including the miscellaneous matter, at the end of December. The whole work makes ten large folio volumes of typewritten matter and contains nearly 3,000 sheets. The total number of names will fall slightly below 40,000. From a census made in 1885 it was estimated that there were about 10,000 species of fossil plants known. It therefore appears that there are about three synonyms to each species. Even in its present condition this bare list of names proves a great saving of time in all the literary work of the office, and could nothing more have been done it would have well repaid the labor of preparing it.

The next step in the compendium work was that of appending to each name in this list the first reference to the plant. This work was begun on the 1st of January, and for several months I devoted an hour or more each day to it. The references could obviously be made only in the form of abbreviations, but those that had been adopted in cataloguing the books were not generally adapted to the present purpose. They were largely symbolic, because an abbreviation has often to be repeated hundreds of times, and therefore it was necessary to make them much too short to be proper in a published list. A new set of abbreviations therefore had to be adopted, which should be to some extent descriptive of the works, and whenever the memoir in which a name is first published occurs in a scientific serial a reference to that serial was necessary. The work, moreover, required that the book itself be carefully consulted in each case, in order to eliminate all typographical and clerical errors. In many cases, too, the earliest reference that has been found is not the absolutely first, and in all such cases search has to be made for the original work. These and many other obstacles and niceties made it necessary that this work should be begun with great care, but as it progressed the difficulties diminished and I was able to avail myself more and more of the services of Miss Schmidt, until at length, in April, I found it possible to delegate the entire work to her, with only some general supervision on my part. As I am dependent upon her as typist in taking from dictation all manuscript and letters, and as she also has charge of all bibliographic and routine work of the office, the time that she can devote to the compendium is very limited; but, considering all this, a fair degree of progress has been made.

Respectfully submitted.

LESTER F. WARD,
Paleontologist.

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

REPORT OF MR. W. A. CROFFUT.

U. S. GEOLOGICAL SURVEY,
EDITORIAL DIVISION,
Washington, D. C., June 30, 1894.

SIR: During the fiscal year ending to-day, I have continued to revise manuscripts, read proofs, and cooperate with the Government Printing Office in getting the publications of the Survey properly to press.

The following table indicates, in part, the output of work during the fiscal year closing:

Manuscript read.	Proof read.
Fourteenth Annual Report, Part II.	Thirteenth Annual Report, Part III.
Monographs XXIV, XXV.	Monographs XXII, XXIII, XXIV.
Bulletins 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124.	Bulletins 102 (in part), 103, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118.
Mineral Resources for 1892 and 1893.	Mineral Resources for 1892 and 1893.
Ten atlas folios.	Five atlas folios.

The revision of the proof has involved the reading of thousands of galleys and pages and the adjustment of illustrations thereto.

During the year the Survey has published:

Twelfth Annual Report, Part I.
Thirteenth Annual Report, Part I.
Thirteenth Annual Report, Part II.
Thirteenth Annual Report, Part III.
Fourteenth Annual Report, Part I.
Mineral Resources for 1892.
Monographs XIX, XXI, and XXII.
Bulletins 97, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117.

The correspondence of this division during the year has been voluminous, including many letters to authors and the Public Printer.

Respectfully, yours,
W. A. CROFFUT,
Editor.

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

REPORT OF PROF. F. W. CLARKE.

U. S. GEOLOGICAL SURVEY,
DIVISION OF CHEMISTRY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of work done in the Division of Chemistry during the fiscal year 1893–'94, by the force consisting of Dr. W. F. Hillebrand, chemist, Mr. George Steiger, assistant chemist, and myself.

Through the first five months of the year I was mostly absent from Washington, under detail by the Secretary of the Interior to represent the Department at the World's Columbian Exposition at Chicago. During that time Dr. Hillebrand was in charge of the laboratory as acting chief. After my return my time was considerably occupied with Exposition business till March. Since then I have been working on the constitution of the natural silicates, and have obtained general results of an interesting character bearing upon the genesis and transformations of some of the most important rock-forming minerals.

In the laboratory the work has followed along routine lines, with very little opportunity for scientific work as such. Dr. Hillebrand, however, has made some investigations upon the quantitative determination of barium and strontium in rock analyses, and also upon the estimation of ferrous oxide. Such work as this, the development of analytical methods, is of obvious value in a laboratory like ours.

In all, 192 analyses have been reported during the year. These include about 40 coals from Wyoming, over 50 rocks from California, 17 rocks from Montana, 17 rocks and 10 clays from Colorado, etc. Many of the analyses have been of the most elaborate kind, and so represent more than the usual amount of labor. The year closes with the work well up to date.

Very respectfully,

F. W. CLARKE,
Chemist.

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

REPORT OF MR. F. H. NEWELL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of work in the Division of Hydrography for the fiscal year ending this day.

The work of this division has been in the line of that of preceding years, investigations of the quantity of water and its fluctuations in the various streams of the country having been carried on as far as the funds at hand would permit. These being less than in past years, there has been a reduction in the amount of field work, and a correspondingly longer time has been spent in the office in the preparation of data for publication.

During the fall of 1893 a personal inspection was made of the gaging stations where records of river height have been maintained for several years. The apparatus for determining the daily heights was examined, and check gagings were obtained to determine whether the rating tables previously constructed could still be used with a fair degree of accuracy. I first proceeded to Montana, and then to the State of Washington, making measurements at points on the Yakima River and its tributaries. Returning again to Montana, gagings were made on the West Gallatin, Madison, and Jefferson rivers, and new rods for noting the height of water were placed. Inspection was then continued at Idaho Falls, Idaho, at Collinston on Bear River, in Utah, and at other localities. From there I proceeded to Colorado and made measurements of the quantity flowing in Arkansas River at points from Canyon to Byron, near the Kansas line. A short time was spent with Mr. G. K. Gilbert, geologist, study being made of the water flowing in the St. Charles River and its possible increase or diminution while flowing across the outcropping edges of the Dakota sandstone. From Colorado inspection work was continued in New Mexico and down to El Paso, Tex., and from there across Arizona to southern California, where, in accordance with instructions from the Secretary of the Interior, I represented the Department at the International Irrigation Convention.

On returning to the office at Washington, D. C., I resumed work on the compilation of data relating to water supply, and in connection with this work facts pertaining to artesian wells were brought together and a systematic cataloguing of deep borings was begun. As illustrating the general results of investigations under my charge, a map showing the mean annual run-off was prepared, this being in form similar to the ordinary maps of mean annual rainfall. Following this, and illustrating in a broad way the relation of topography and run-off to vegetation, a second general map was compiled showing what is known of the distribution of the wooded areas in the western part of the United States.

During the winter it was determined to prepare a map showing the present location of the public lands of the United States, and for this purpose a number of assistant topographers were detailed to aid in assembling the scattered data, obtained mostly from the records of the General Land Office. This compilation was pushed rapidly to completion, resulting in a map showing the relative area and position of the vacant public lands and bringing out the relation of these lands to the water supply of the country and the dependence of their development upon the proper utilization of this supply when its character shall be fully known.

May 14, 1894, field work was resumed, mainly in the basin of Arkansas River in Colorado and Kansas, and to a small extent in that of the Rio Grande, and also in Utah. In particular, gagings were made of Arkansas River at the time of the extraordinary floods of May 30 and 31, and of June 5 and 6, both of which caused great destruction of property and some loss of life, especially in the vicinity of Pueblo, Colo. The facts obtained serve to exhibit the fluctuations of rivers of this class and illustrate the liability of the occurrence of overwhelming quantities of water at unexpected times. This work was brought to a close at the end of the fiscal year.

The investigation of the hydrography of the Potomac has been continued, and new stations have been established at points higher up on the main river and tributaries. This work has been carried on largely through the efforts of Mr. Cyrus C. Babb, assisted by others who have generously contributed to the success of this important and interesting study.

The results of field and office work are shown more fully in my paper on "Results of Stream Measurements," to be found in Part II of the Fourteenth Annual Report of the Survey.

I have the honor to be your obedient servant,

F. H. NEWELL,
Topographer.

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

REPORT OF MR. BAILEY WILLIS.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit a report of the work of editing geologic maps for the fiscal year ending to-day.

A year ago, being relieved of the administrative control of the Appalachian Division, I received instructions to give special attention to the publication of geologic maps, and also, so far as might be possible without conflicting with my duties as editor, to conduct surveys in the Puget Sound basin. It was found undesirable that I should long absent myself from the office, and no field work was undertaken. With the exception of absences on leave and a few days of January spent in Cambridge, Mass., in consultation with Professors Shaler and Davis in regard to their geologic maps, I have been constantly in Washington, engaged in editing and revising maps for the press. Concerning the purpose and character of these maps, and the conditions of their publication, a full statement appears in the Director's report [on pp. 78–90 of this volume].

The preliminary editions of the Chattanooga and Kingston folios contained a general statement of Appalachian history. During the autumn I rewrote this outline, but finding that the limits necessarily placed upon the article rendered it unsatisfactory, I withdrew it from the atlas, and it is now proposed to issue a bulletin on the subject.

Much thought has been given to other descriptions appearing in the folios of the atlas, particularly the general accounts of geology in the Livingston folio, Montana, in the folios of the Gold Belt, California, and in those relating to the geology of the crystalline rocks and glacial deposits of western Massachusetts.

A general geologic map of the United States, on the scale of 40 miles to 1 inch, was prepared by Prof. W. J. McGee in the spring of 1893. In January, 1894, it was revised by myself and forwarded to the Engraving Division. It is now being proof-read in plate proof.

A geologic map of the State of New York, prepared under the direction of the State geologist, Prof. James Hall, by Mr. N. H. Darton, of the U. S. Geological Survey, was placed in my hands in February. The plate proof has recently been read.

Thus my work for the past fiscal year has been to a great extent devoted to seeking the best mode of expressing geologic facts in maps and descriptions. It has been performed jointly with Mr. S. J. Kübel, chief engraver, whose skillful management of the technical processes has removed every difficulty raised by the geologic problems.

Respectfully submitted.

BAILEY WILLIS,
Geologist and Editor of Geologic Maps.

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

REPORT OF MR. DE LANCEY W. GILL.

U. S. GEOLOGICAL SURVEY,
DIVISION OF ILLUSTRATIONS,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following statement of work done in the Division of Illustrations during the fiscal year ending to-day.

The personnel of the division is as follows: John L. Ridgway, Daniel P. O'Hare, H. Hobart Nichols, Daniel W. Cronin, F. W. von Dachenhausen, Wells M. Sawyer, H. C. Hunter, and Frances Wieser.

Mr. Ridgway's work has been principally the preparation of paleontologic drawings, and as my assistant he has rendered valuable aid in the general supervision of the drafting. Mr. O'Hare has been engaged in reading geologic and topographic map proofs. Mr. Nichols's work has been the preparation of geologic landscapes and the retouching of photographs. Mr. Cronin has been employed in the drawing of miscellaneous maps and diagrams. Messrs. von Dachenhausen and Sawyer have been engaged in miscellaneous diagram and paleontologic work. Mr. Hunter and Miss Wieser have been employed temporarily in the preparation of drawings of paleontologic specimens. Mr. W. F. Hopson has been similarly employed and has been working under the supervision of Prof. Marsh, at New Haven, Conn.

Drawings to the number of 1,642 were produced during the year and were classified as follows:

Paleontologic drawings	1,200
Geologic landscapes	66
Geologic maps	35
Geologic sections and diagrams	224
Miscellaneous drawings	117

Engraved proofs of 850 drawings have been received from the Public Printer during the year. The criticism and revision of this material has been carried on as in previous years. The printed editions of all the lithographic work for the publications of the Survey have been examined by me, and the imperfect work rejected. Original drawings representing the illustrations for one annual report, two monographs, and four bulletins were transmitted to the Public Printer during the year. These illustrations were marked for reproduction by the following processes:

Chromo-lithography	37
Lithography	1
Photo-engraving	148
Half-tone engraving	86

The photographic laboratory is under the supervision of Mr. J. K. Hillers, assisted by C. C. Jones, John Erbach, and Charles A. Ross, photographic printers. The following statement shows the number of negatives and prints made during the year:

Negatives.		Prints.	
Size.	Number.	Size.	Number.
28 by 34	103	28 by 34	426
22 by 28	59	22 by 28	198
20 by 24	299	20 by 24	2,221
14 by 17	145	14 by 17	519
11 by 14	171	11 by 14	1,455
8 by 10	177	8 by 10	4,740
4 by 5	560	5 by 8	200
		4 by 5	1,393
Total	1,514	Total	11,152

Very respectfully,

De Lancey W. Gill.

Hon. J. W. Powell,
Director U. S. Geological Survey.

REPORT OF MR. S. J. KÜBEL.

U. S. Geological Survey,
Engraving Division,
Washington, D. C., June 30, 1894.

Sir: The following report of the work done by the Engraving Division during the fiscal year ending June 30, 1894, is respectfully submitted.

During the past year the results of the experimentation and preparation in geologic map-making of the preceding years were put to practical use.

Up to the close of the fiscal year ending June 30, 1893, much of the time of this division was consumed in the solution of questions bearing upon the production of geologic folios in their finally accepted arrangement. This work of preparation embraced the selection and engraving of plates of geologic symbols, the selection and testing of colors to be employed in their printing, the question of paper to be used, and a number of other details. A definite color-scheme was adopted, as was also the scheme of patterns, and both schemes are now being applied in the routine work of printing.

The most important step toward the economical prosecution of work was the acquisition of suitable working space in a building adjoining the main office building of the Survey. Immediately upon this acquisition in September, 1893, expansion followed along different lines of work.

Two steam lithographic presses were added to the two already in use, and a typographic steam press was installed. The division is now sufficiently well equipped to promptly meet the requirements of the work assigned to it. It is estimated that, in connection with the work of printing the regular office editions of topographic atlas sheets, about thirty geologic folios in editions of 5,000 each can be issued annually.

TOPOGRAPHIC SHEETS.

Twenty topographic atlas sheets were engraved, and work has been begun on thirteen new sheets. Many of these embrace areas in the mountain regions of New York, Vermont, and New Hampshire.

In January, 1894, a contract for the engraving of eight atlas sheets was let to Messrs. Evans & Bartle, contracting engravers of this city. All the engraved plates of this contract have been delivered to this office.

During this year the same firm delivered forty-nine sets of plates of topographic atlas sheets under their contract of June, 1892, and thus completed their contract. The total number of complete sheets added during the year, therefore, is sixty-nine.

ENGRAVING OF GEOLOGIC FOLIOS.

The most important work, and that to which the most time and study was given, was the making of geologic folios.

The following were completed in editions of 4,000 each:

Livingston, Mont.
Placerville, Cal.
Sacramento, Cal. (second edition).
Ringgold, Tenn. (second edition).
Kingston, Tenn. (second edition).

The following are in preparation:

Anthracite, Colo.
Crested Butte, Colo.
Estillville, Va.-Ky.-Tenn.
Pikes Peak, Colo.
Jackson, Cal.
Sewanee, Tenn.
Harpers Ferry, Va.-W. Va.-Md.
Prince Frederick, Md.
Brandywine, Md.

Almost the entire energy of the corps is now centered upon the production of these folios, and precedence is given them over all other work.

In June, 1893, Mr. Bailey Willis was appointed editor of geologic maps, and since he entered upon his duties the entire subject of geologic-map production has received great stimulation.

MISCELLANEOUS WORK.

The engraving of the geology of the United States on the nine-sheet base map, scale 1:2500000, was begun, as was also a reduction of the same on the smaller base map, scale 1:7000000.

The work of engraving the geology of the New York State map, in six sheets, scale 1:316800, was carried on, and 500 copies of the base of this map were printed.

In accordance with the plan of cooperation entered into by this office and the commissioners of the State of Connecticut, an edition of 2,000 copies of 33 topographic sheets, comprising the entire map of Connecticut, was printed. The work was done upon the presses of this division, by its members, and the cost of labor and material was met by the commissioners of Connecticut.

Similarly 1,000 copies of the wall map of Connecticut, scale 1: 125000, were printed for that State.

A map entitled "New York and Vicinity," combining portions of nine topographic atlas sheets into a single sheet 36 by 52 inches in size, was printed in an edition of 2,000 copies.

By the same plan of combining atlas sheets special maps were made of "Albany and vicinity" and "Niagara Falls and vicinity," and large editions of both were printed.

Editions varying from 500 to 1,000 were printed of 330 topographic atlas sheets, and the total number of copies of atlas sheets delivered was 180,000.

Recently some trials were made with a view to ascertaining the practicability of using aluminum plates lithographically for our purposes, but no conclusion has yet been reached.

OFFICE FORCE.

For the greater part of the year 42 persons were employed. They may be classified as follows: engravers, 14; printers, 18; assistants, 10.

The stock of engraved plates is rapidly increasing, and this division is now charged with the care, storage, and revision of 2,400 plates of atlas sheets, including bases for geology, and 90 plates of miscellaneous maps.

Respectfully submitted.

S. J. KÜBEL,
Chief Engraver.

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

REPORT OF DR. DAVID T. DAY.

U. S. GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS AND TECHNOLOGY,
Washington, June 30, 1894.

SIR: I have the honor to report that during the fiscal year 1894 the work of the Division of Mining Statistics and Technology has consisted chiefly of the preparation of two volumes of the series "Mineral Resources of the United States." On July 1, 1893, much of the work of gathering the statistics for the volume "Mineral Resources of the United States, 1892," had been completed, and several chapters had been published in separate form. The completion of the various chapters of this report, including editing, proof reading, etc., occupied the attention of the division for the first six months. The work of publishing the tenth volume of the series, "Mineral Resources of the United States, 1893," was then actively taken up and carried to a successful finish during the last six months of the fiscal year. Therefore, two complete volumes were published within the year.

In addition to publishing separately, in advance of the volume, several individual chapters of the report for 1893, the entire volume was sent to the printer on the first day of June, and now, at the close of the year, it has been stereotyped and printed and is in the hands of the binder. From this volume the following brief synopsis of the condition of the mineral industry during 1893 is taken.

The total value of the mineral products of the United States in 1893 was the smallest since 1889. It was $609,821,670, compared with $688,616,954 in 1892, a decline of 11.45 per cent. In 1892 there was an increase of 30½ millions, or 4.67 per cent over 1891. The decline in value was most conspicuous in pig iron and structural materials, but most other minerals also declined in the amount and the value of the product, the exceptions being gold, anthracite coal, aluminum, phosphate rock, and gypsum. Bituminous coal showed a slight increase in quantity, but the normal increase was checked and the total value was less than in 1892. Petroleum increased in value but decreased in quantity. Salt, quicksilver, and several smaller products increased in quantity, but shared the usual decline in value. This general decline was attributed to the financial depression and the consequent decreased consumptive demands. It was conspicuous only during the last half of the year, as considerable time is necessary for affecting the mining industry, and as it is correspondingly slow in recovering, its effect will be equally pronounced in 1894.

METALS.

Iron and steel.—Pig iron declined from 9,157,000 long tons in 1892 to 7,124,502 tons in 1893. The total value declined over $46,000,000, or from $131,161,039 in 1892 to $84,810,426 in 1893. The limestone used for iron flux amounted to 3,958,055 long tons, worth $2,374,833.

The total product of iron ores fell to 11,587,629 long tons, worth $19,265,973, an average value of $1.66 at the mines.

In 1892 the product was 16,296,666 long tons, worth $33,204,896, or $2.04 per ton at the mines.

Gold and silver.—The gold product increased from 1,596,375 Troy ounces with a coining value of $33,000,000 in 1892 to 1,739,081 ounces worth $35,950,000 in 1893. This product is the largest since 1886. The increase was due chiefly to the new mines in Colorado. Silver production was very active in the first part of 1893, due to the effort of smelters to work up accumulated stocks. The heavy decline in the last part of the year made the total less than in 1892 by 3,500,000 ounces, as follows: 1892, 63,500,000 ounces, coining value $82,099,150; 1893, 60,000,000 ounces, coining value $77,575,757.

Copper.—The industry took little notice of the depressed money market and the decreased consumption. The product from American ores aggregated 337,416,848 pounds, against 353,275,742 pounds in 1892. In addition, 7,723,387 pounds were produced in 1893 from imported pyrites. The necessary expenditures were also made for keeping up future production.

Lead.—Product: 163,982 short tons, worth $11,839,590, compared with 173,654 short tons in 1892, worth $13,892,320.

Zinc.—The rapidly increasing product of late years was checked and a slight decline noted; product, 78,832 short tons, worth $6,306,560, compared with 87,260 short tons, worth $8,027,920, in 1892.

Quicksilver.—The product showed a noteworthy increase from 27,993 flasks in 1892 to 30,164 flasks in 1893. The price fell, making the total value $1,108,527 in 1893, compared with $1,245,689 for the smaller product of 1892. The increased product came chiefly from the New Almaden, Mirabel, and Ætna mines.

Manganese.—The decline in quantity from 13,613 long tons in 1892 to 7,718 long tons in 1893 was offset by the following imports: 67,717 long tons in 1893 and 58,364 long tons in 1892. The product of manganiferous iron, silver, and zinc ores shows change.

Aluminum.—The usual increase in product continued. In 1893 339,629 pounds were made, chiefly by the Pittsburg Reduction Company; it was valued at $266,903 in the producer's hands. The largest single use is for adding to steel before casting. It is also used for improving iron castings, for ornamental fancy articles, and for aluminum cooking utensils. The latter began to be generally introduced during the year. The quality of aluminum bronze castings is improving.

The Southern deposits of bauxite furnish more and more of the raw material. The Arkansas bauxite deposit will probably be developed in 1894 for making alum.

Tin.—More careful examinations of the Kings Mountain, North Carolina, locality furnish indications of considerable ore which may yield 3 per cent. No work was done at the other deposits except running the concentrator at Hill City, S. Dak., for about a month. Eight thousand nine hundred and thirty-eight pounds of tin were smelted and sold from part of the concentrates.

Nickel.—The United States product was from Lancaster Gap, Pennsylvania, and from Missouri. It is estimated at 49,399 pounds, worth $22,197, a marked decline from 1892, due to Canadian competition. The Nevada and Oregon mines have not become producers, but prospecting and development continues. The New Caledonia mines increased their product and accumulated stock.

Antimony.—The value decreased from $56,466 to $45,000 in 1893. The product came from Nevada, and was smelted in San Francisco.

Platinum.—The product from the gold placers is still insignificant. The production in 1893 was 75 ounces.

FUELS.

Coal.—The product of all kinds of coal in 1893 was 162,814,977 long tons, or 182,352,774 short tons, valued at $208,438,696, against 160,115,242 long tons, or 179,329,071 short tons, valued at $207,566,381, in 1892. The increase in 1893 was 2,699,735 long tons, or 3,023,703 short tons, in quantity, but, owing to a decline in the price of bituminous coal, the result of overproduction during the latter part of the year, the value increased but $872,315. The product in 1893 consisted of 48,185,306 long tons, or 53,967,543 short tons of anthracite coal from Pennsylvania, an increase from 1892 of 1,334,856 long tons, or 1,495,039 short tons, and of 114,629,671 long tons, or 128,385,231 short tons of bituminous (including scattering lots of anthracite from Colorado, New Mexico, and Virginia), an increase over 1892 of 1,364,879 long tons, or 1,528,664 short tons. The value of Pennsylvania anthracite increased $3,245,078, the average price, in spite of the industrial depression, advancing from $1.92 to $1.94 per ton. The value of bituminous coal decreased $2,372,763, the average price declining from 99 cents per ton in 1892, to 96 cents in 1893. In stating the value of anthracite the marketable product only is included; that is, the amount of coal used at the collieries, which is merely culm or slack which would otherwise be wasted, while included in the product, is not included in the value. This item of colliery consumption in 1893 was 4,016,709 long tons, or 4,498,714 short tons. The value of bituminous includes all grades of coal produced except what is thrown on the dump and neither sold nor used.

Coke.—The total product of coke in the United States in 1893 was 9,460,310 tons as compared with 12,010,829 tons in 1892. This great reduction is due to the depression in the blast-furnace industry. Coke-made pig iron in 1893 was 5,390,184 tons as compared with 6,822,266 tons in 1892, and pig iron made with anthracite and with mixed anthracite and coke aggregated 1,347,529 tons in 1893 as compared with 1,797,113 tons in 1892. This would account for a reduction of about

2,000,000 tons of coke. The remainder of the decrease is due to the falling off in demand at foundries and other works where coke is used. Pennsylvania is still the chief coke-producing State, contributing 65·8 per cent of the total, and Alabama is second, contributing 12·2 per cent.

Petroleum.—The chief features of interest in 1893 were: (1) The great decline in production of the older fields and the increase of the newer. (2) The decline in stocks held at the wells. (3) The increase in price. (4) The increase in exports. (5) The success in refining limestone oils.

Pennsylvania declined from 27,149,034 barrels of 42 gallons in 1892 to 19,283,122 barrels in 1893. Lima, Ohio, fell off from 15,169,507 barrels in 1892 to 13,646,804 barrels in 1893. On the other hand the production of West Virginia increased from 3,810,086 barrels in 1892 to 8,445,412 barrels in 1893.

Indiana increased from 698,068 barrels in 1892 to 2,335,293 barrels in 1893. The total product for all States declined from 50,509,136 barrels in 1892 to 48,412,666 barrels in 1893. The year 1891 marked the highest output, it being 54,291,980 barrels. This was the year of the remarkable product of the McDonald field in Pennsylvania.

The average value of certificate oil in the Pennsylvania fields was 64 cents a barrel compared with 55⅝ cents in 1892; an increase of 8⅜ cents. The price for Lima oil advanced from 36⅝ cents in 1892 to 47¼ cents in 1893, an increase of 10⅝ cents.

The total exports of petroleum in the calendar year 1893, including crude, refined, and residuum was 804,221,230 gallons, the largest export recorded, and an increase of nearly 60,000,000 gallons compared with 1892. All forms of oil except lubricating oil shared in the increase.

Natural gas.—The consumption of natural gas is limited more and more to domestic use. Only in Indiana has consumption increased for manufacturing purposes. Another feature of the situation is the increase in price to consumers. The total value of the product in 1893 was $14,346,250; in 1892, $14,800,714.

STRUCTURAL MATERIALS.

Stone.—The value of the total product of stone of all kinds decreased to $33,865,573 in 1893 from $48,706,625 in 1892. The depression was very great in the last half of the year and continues in 1894. The product of lime is an estimate, and is probably too high; the figures are merely kept as the best available.

Soapstone.—Soapstone in slabs, etc., aggregated 21,071 short tons in 1893, worth $255,067. Fibrous talc amounted to 35,861 short tons, worth $403,436. Both industries show the usual decline.

Clays.—The returns from the division of manufactures in the Census Office indicate that the value of brick clay in 1890 was $8,500,000, and about $9,000,000 in 1893. The total value of the finished brick, tile, and terra cotta aggregated $67,000,000. The production of potter's clay of all qualities aggregated 400,000 tons, worth $900,000.

Cement.—Natural rock cement decreased slightly, i. e., to 7,411,815 barrels, worth $5,104,708; artificial Portland cement to 590,652 barrels, worth $1,158,138.

Feldspar.—The product increased slightly, aggregating 18,391 long tons, worth $68,037; the value shows the usual decrease.

Flint.—Product in 1893, 29,671 long tons, worth $63,792.

Asphaltum.—The product came chiefly from California, with small amounts from Utah and Kentucky. The total in 1893 includes the ozocerite product of Utah, and amounted to 47,779 short tons, worth $372,232. The product of asphaltum alone in 1892 was 87,930 short tons, worth $445,375.

ABRASIVE MATERIALS.

Millstones.—The value decreased from $23,417 in 1892 to $16,645 in 1893. The product came from New York, Pennsylvania, and Virginia.

Grindstones.—Value in 1892, $272,244; in 1893, $338,787, including in the latter figure $19,159 worth of whetstones made from sandstone, chiefly in Ohio.

Corundum and emery.—The product remained nearly stationary, i. e., 1,771 short tons, worth $181,300 in 1892, and 1,713 short tons, worth $142,325 in 1893.

Novaculite.—The Arkansas, New Hampshire, and other whetstones and oilstones produced in 1893 from novaculite had a value of $135,173, against $146,730 in 1892. This does not include the sandstone products of Ohio.

MINERALS USED FOR CHEMICAL PURPOSES.

Phosphate rock.—Florida produced 438,804 long tons and South Carolina 502,564 tons; total value, $4,136,070. The chief event of importance was the cyclone of August 27, which wrecked the river phosphate industry in South Carolina and raised the price for Florida rock.

Marls.—The local use of marls in New Jersey, Virginia, and Alabama continues to decrease, being displaced by commercial fertilizers.

Gypsum.—Stocks decreased in 1892, due to the manufacture of staff for the World's Fair buildings. This caused the increased production of 1892 to continue. The product in 1892 was 246,374 short tons, worth $671,548; in 1893 it was 253,615 short tons, worth $696,615.

Salt.—The product in 1892 was 11,698,890 barrels (of 280 pounds each); this increased slightly in 1893 to 11,816,772 barrels. The total value shows a decrease from $5,654,915 in 1892 to $4,054,668. This decrease is largely apparent only, since the cost of package is omitted in the latter year.

Bromine.—The market price in London advanced quite significantly, due to a better understanding between producers, so that 348,399 pounds, the product of 1893, showed a total value of $104,520, against only $64,502 for 379,480 pounds in 1892.

Iodine.—Search is being made for large quantities of salt brines containing even traces of iodine, with a view to a new process for extracting it.

Sulphur.—The product is still light and limited to the western mines. Quantity in 1893: 1,200 short tons, worth $42,000 at Salt Lake City. The product in 1892 was 2,688 tons.

Pyrites.—The product declined from 114,717 long tons in 1892, worth $305,191, to 83,277 long tons, worth $275,302, in 1893. The imports increased. New sources of supply are being developed in North Carolina.

Borax.—The product declined to 8,699,000 pounds, worth $652,425.

Fluorspar.—Price showed a slight decline with a small increase in quantity to 12,400 short tons, worth $84,000.

MINERAL PIGMENTS.

Barytes.—Product 28,970 short tons, worth $88,506, a decrease from 32,108 tons in 1892. There is some promise of an increase again in 1894.

Metallic paint.—The product of metallic paint decreased from 30,211 short tons, valued at $452,966, in 1892, to 19,950 short tons, worth $297,189, in 1893.

Ocher, umber, etc.—The product of ocher decreased to 10,517 short tons, worth $129,393. Of umber the product was about the same as in 1892, though the value increased slightly. Sienna decreased from 500 tons to 150 tons. The amount of soapstone ground for paint was 100 tons. Of mineral black the product was 70 tons.

Venetian reds.—The product declined from 4,900 short tons, worth $106,800, to 3,214 tons, worth $64,400.

Cobalt oxide.—Including the exports contained in speiss, the total product was 8,422 pounds, worth in the condition in which it was first sold $10,346. The price for pure cobalt oxide ready for pottery or paint use was $2 per pound.

Zinc white.—The product declined slightly, as follows: 24,059 short tons in 1893 against 27,500 tons in 1892. Prices remained steady.

Graphite.—The product, 843,103 pounds, includes the crude material mined for crucibles and all other purposes as well as that for pencils. It is valued at $63,232 in the state in which it was first mined.

Chromic iron ore.—The product was 1,450 long tons, all from Glenn County, Cal. It was worth $21,750 in San Francisco. The consumption is chiefly supplied by imports from Asia Minor.

MISCELLANEOUS.

Precious stones.—The value of rough gems found in the United States decreased from $312,050 in 1892 to $264,041 in 1893. The principal items of interest were the discovery, in Wisconsin, of a diamond weighing $3\frac{1}{16}$ carats, and the large sale of American turquoise.

Mica.—The industry is still crippled by irregular mining methods. The product was 66,971 pounds in 1893, worth $88,929.

Asbestos.—Deposits of chrysotile somewhat similar to the Canadian have been found near Casper, Wyo., but need development. The domestic product from California was insignificant, i. e., 50 tons, worth $2,500.

Infusorial earth.—The product decreased. Its value in 1892 was $43,655, which fell to $22,582 in 1893.

Magnesite.—The deposits in California yielded 704 short tons in 1893, part of which was calcined and part sold crude. The price in San Francisco was $10 per ton.

Mineral waters.—The statistics are limited to the actual amount sold; these show a gain from 21,876,604 gallons in 1892 to 23,544,495 gallons in 1893, but, as usual, values declined, thus: 1892, $4,905,970; 1893, $4,246,734.

The usual correspondence, including answers to many requests for statistical and technical information concerning the mines of the United States, was carried on.

For a large portion of the fiscal year Mr. W. A. Raborg, of the staff of this division, was temporarily engaged as one of the chief assistants in the Department of Mines and Mining, World's Columbian Exposition, by resignation from the U. S. Geological Survey. He was reappointed and reentered upon his duties in this office on December 6, 1893. In addition to the various special contributors to the volume, the office staff, in addition to myself, has remained as follows: Mr. E. W. Parker, Mr. W. A. Raborg, and Mr. Jefferson Middleton.

During the greater part of the time from May 1 to October 31 the chief of the division was engaged in a study of the mining exhibits at the World's Columbian Exposition and in collecting there such information concerning the mineral resources of the United States as proved to be new.

Very respectfully, your obedient servant,

DAVID T. DAY,
Geologist in Charge.

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

REPORT OF MR. CHARLES C. DARWIN.

U. S. GEOLOGICAL SURVEY LIBRARY,
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of the work done in the library during the fiscal year ending to-day.

During this period 2,328 books, 3,921 pamphlets, and 220 maps were added to the library, and increased its total contents in books, pamphlets, and maps to 110,343.

All the most important of these have been catalogued under author entry, and, with the exception of a large contribution of descriptive publications donated by exhibitors at the Columbian Exposition, that catalogue is complete to date and comprises more than 85,000 cards.

The number of books used has been over 1,000 a month. While fewer books have been drawn out, the average has been maintained by the larger number consulted by readers in the library.

The following table gives in detail the growth of the library for the year:

Contents of the library, June 30, 1894.

BOOKS.			
On hand June 30, 1893:			
Received by exchange	22,781		
Received by purchase	9,561		
		32,342	
Received during the past year:			
By exchange	1,624		
By purchase	704		
		2,328	
			34,670
PAMPHLETS.			
On hand June 30, 1893:			
Received by exchange	40,740		
Received by purchase	4,977		
		45,717	
Received during the past year:			
By exchange	3,519		
By purchase	402		
		3,921	
			49,638
MAPS.			
Geologic and topographic maps:			
On hand June 30, 1893		25,815	
Received during the year		220	
			26,035
Total number of books, pamphlets, and maps			110,343

EXCHANGES.

A total of 5,363 books, pamphlets, and maps have been received during the year by exchange; 2,936 volumes of the Eleventh Annual Report have been distributed to all correspondents; and 4,792 maps have been sent to those entitled to map exchange.

The exchange list, which has been continually enlarged in the lines of the library's needs, has undergone this year a preliminary revision, and will be corrected and printed as soon as the new printing bill shall determine the number of Survey publications available for exchange purposes.

I am, sir, yours, with great respect,

CHAS. C. DARWIN,
Librarian.

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

REPORT OF MR. JOHN R. WALSH.

U. S. GEOLOGICAL SURVEY,
MISCELLANEOUS DIVISION.
Washington, D. C., June 30, 1894.

SIR: I have the honor to submit the following report of work for the fiscal year ending June 30, 1894.

The general register shows 2,324 letters received, all of which were duly briefed, indexed, appropriately referred or responded to, and when finally disposed of systematically filed for preservation. The number above named is slightly exceeded by the number of letters recorded and forwarded, about one-third of such letters sent having been prepared in this division.

The appointment records show the following changes in the personnel of the bureau during the year:

Original appointments	68
Reappointments	5
Promotions	22
Reductions	2
Transfers	3
Separations from the service	23

The keeping of these records requires considerable time and care, six separate entries, on as many forms (for the information of all concerned), being required in every change of status.

Three reports to the Secretary of the Interior are prepared at stated intervals during the year, namely: the official personnel, noting changes monthly in the order of occurrence; the monthly efficiency record of clerical assistants; and the semi-annual report of leaves of absence, compiled from the time records of the division.

Copy for the biennial "Official Register of the United States" (Blue Book) was submitted as usual, as was the Survey's portion for incorporation in the annual "Register of the Department of the Interior" for 1894. Data relating to appointment and kindred affairs were listed and placed in convenient shape for departmental and office purposes. Two detailed statements concerning the status of all employees were arranged, forms having been supplied by the Joint Commission of Congress to Inquire into the Status of Laws organizing the Executive Departments. The tasks named consumed much time, and the degree of accuracy and careful attention demanded by each was proportionately great.

In addition to the routine work, including requisitions for printing, the keeping of numerous memoranda, responding to calls on subjects connected with the files, etc., a large amount of material, consisting of technical papers and correspondence foreign to the regular work of the division, was typewritten.

Mr. James T. McClenahan, copyist, who succeeded Mr. W. M. McDevitt, rendered faithful and efficient service.

I am, with great respect,

JOHN R. WALSH,
In Charge.

TO THE DIRECTOR,
U. S. Geological Survey.

REPORT OF MR. JNO. D. M'CHESNEY.

U. S. GEOLOGICAL SURVEY,
Washington, D. C., July 9, 1894.

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, 1894, amounting to $436,092.40.

Very respectfully,

JNO. D. MCCHESNEY,
Chief Disbursing Clerk.

TO THE DIRECTOR,
U. S. Geological Survey.

ANALYSIS OF DISBURSEMENTS.

Under the following heads appear the total expenditures under the various appropriations for the U. S. Geological Survey:

1.	Salaries, office of the Director	$35, 279. 87
2.	Salaries of scientific assistants	29, 883. 71
3.	Skilled laborers and various temporary employees	12, 995. 53
4.	Topography	192, 843. 36
5.	Geology	66, 127. 70
6.	Paleontology	9, 355. 31
7.	Chemical and physical researches	4, 484. 72
8.	Preparation of illustrations	12, 450. 51
9.	Mineral resources of the United States	11, 892. 52
10.	Books for library	1, 835. 52
11.	Rent of office rooms	4, 199. 88
12.	Geological maps of the United States	54, 743. 77
	Total	436, 092. 40

RECAPITULATION.

	Salaries, office of the Director.	Geological maps of the United States.	General expenses of the Geological Survey.	Total.
Appropriation for fiscal year ending June 30, 1894	$35, 540. 00	$55, 000. 00	$359, 100. 00	$449, 640. 00
Expended as per detailed statement herewith	35, 279. 87	54, 743. 77	344, 753. 49	434, 777. 13
Bonded railroad accounts settled at U. S. Treasury			1, 315. 27	1, 315. 27
Balance on hand	260. 13	256. 23	13, 031. 24	13, 547. 60

DETAILED STATEMENT OF EXPENDITURES.

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey, during fiscal year 1893-'94.

SALARIES, OFFICE OF THE DIRECTOR.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1893.				
July 31	1	William N. Thomas	Services, July 1-19, 1893	$30.98
31	2	James J. Seymour	Services, July, 1893	40.40
31	3	Pay roll of employees	......do	2,918.60
Aug. 31	1	......do	Services, Aug., 1893	2,967.15
Sept. 15	1	Lorenzo S. Brown	Services, Sept. 1-15, 1893	24.46
25	2	William S Sheets	Services, Sept. 1-24, 1893	54.78
30	3	Pay roll of employees	Services, Sept., 1893	2,819.28
Oct. 16	1	Jeremiah M. Butler	Services, Oct. 1-15, 1893	19.57
20	2	W. S. Peabody	Services, Oct. 1-20, 1893	163.04
31	3	R. T. Hill	Services, Oct. 21-31, 1893	89.66
31	4	Pay roll of employees	Services, Oct., 1893	2,696.49
Nov. 30	1	......do	Services, Nov., 1893	2,898.60
Dec 31	1	J. W. Green	Services, Dec., 1893 (14 days)	27.39
31	2	Pay roll of employees	Services, Dec., 1893	2,932.60
1894.				
Jan 11	1	J. W. Green	Services, Dec., 1893 (17 days)	33.21
31	2	Pay roll of employees	Services, Jan., 1894	3,060.30
Feb. 28	1	......do	Services, Feb., 1894	2,694.33
Mar. 31	1	......do	Services, Mar., 1894	2,957.00
Apr. 30	1	......do	Services, April, 1894	2,896.38
May 31	1	......do	Services, May, 1894	3,026.30
June 30	1	......do	Services, June, 1894	2,929.35
		Total		35,279.87

GEOLOGICAL MAPS OF THE UNITED STATES.

1893.				
July 21	1	George Meier & Co	Engraver's supplies	$100.75
25	2	......do	......do	6.00
31	3	Pay roll of employees	Services, July, 1893	1,767.76
Aug. 4	1	U. S. Electric Lighting Co	Use of current, July, 1893	25.00
5	2	H. Hoffa	Engraver's supplies	40.96
7	3	S. J. Kübel	Traveling expenses	44.50
8	4	Charles G. Stott & Co	Engraver's supplies	4.20
11	5	George Meier & Co	......do	15.60
11	6	Charles Hellmuth	......do	37.50
9	7	Z. D. Gilman	......do	25.15
16	8	Adams Express Co	Freight charges	1.75
31	9	Pay roll of employees	Services, Aug., 1893	1,862.32
Sept. 9	1	H. Hoffa	Engraver's supplies	61.85
15	2	U. S. Electric Lighting Co	Use of current, Aug., 1893	25.00
15	3	Robert Mayer & Co	Lithographic stones	68.11
15	4	United States Express Co	Freight charges	1.70
15	5	L. D. Keane	Services, Sept. 1-15	13.50
23	6	H F Freeman	Services, Sept. 12-16	7.50
23	7	Charles Lewis	Services, Sept. 19-21	4.50
30	8	Walter Williamson	Services, Sept. 25-30	8.25
30	9	W. E. Maloney	Services, Sept. 11-30	42 50
30	10	L. W. Timmons	Services, Sept. 8-30	47.50
30	11	Pay roll of employees	Services, Sept., 1893	1,919.59
30	12	U S. Electric Lighting Co	Use of current, Sept., 1893	25.00
Oct. 9	1	George Meier & Co	Lithographic hand press	114.00
9	2	Peter Adams Co	Lithographic paper	368.10
9	3	W. G. & G. Greenfield	Stationary engine	465.00
9	4	The Fuchs and Lang Manufacturing Co.	Engraver's supplies	18.00
10	5	Ernest Kubel	Electrotyping	285.00
10	6	Adams Express Co	Freight charges	.40
10	7	......do	......do	.70
18	8	George W. Knox's Express	Freight charges and hauling	6.18
18	9	William H. Arneth	Engraver's supplies	17.50
25	10	Peter Adams Co	Lithographic paper	173.88

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GEOLOGICAL MAPS OF THE UNITED STATES—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1893.				
Oct. 25	11	James Lockhead	Water tank	$46.61
27	12	James K. Cleary	Engraver's supplies	1.50
27	13	John D. McChesney	Traveling expenses	15.75
31	14	W. E. Maloney	Services, Oct. 2–7, 1893	15.00
31	15	W. Williamson	Services, Oct. 2–12, 1893	9.75
31	16	L. W. Timmons	Services, Oct. 2–21, 1893	42.50
31	17	Pay roll of employees	Services, Oct., 1893	1,955.41
Nov. 7	1	U. S. Electric Lighting Co	Use of current, Oct. 1–5, 1893	4.03
7	2	Z. D. Gilman	Engraver's supplies	13.80
7	3	Royce & Marean	do	39.00
7	4	Fuchs & Lang Manufacturing Co.	do	24.54
7	5	George Meier & Co	Gearing on lithographic press	48.90
11	6	E. E. Jackson & Co	Lumber	161.20
11	7	W. B. Moses & Sons	Engraving supplies	2.25
11	8	George W. Knox's Express	Freight charges and hauling	1.01
11	9	do	Services of men and teams	185.75
16	10	William D. Clark & Co	Engraver's supplies	13.06
17	11	Charles Hellmuth	do	22.00
17	12	L. H. Schneider's Son	do	16.43
18	13	Peter Adams Co	Lithographic paper	3,206.13
21	14	Royce & Marean	Engraver's supplies	1.50
21	15	The Norris Peters Co	Services	39.00
21	16	The Pennsylvania R. R. Co	Transportation of assistant	10.00
24	17	W. S. Hardesty	Traveling expenses	3.75
24	18	The Fuchs & Lang Manufacturing Co.	Lithographic stones	581.84
28	19	Peter Adams Co	Lithographic paper	1,221.74
30	20	Pay roll of employees	Services, Nov., 1893	2,114.70
30	21	J. F. Manning	Engraver's supplies	21.00
Dec. 2	1	E. E. Helm	Services, Nov. 28–29, 1893	4.20
6	2	Smith, Dixon & Co	Engraver's supplies	38.00
6	3	Z. D. Gilman	do	38.24
9	4	J. E. Hurley	Labor and material	1,052.71
9	5	N. A. Poole	Engraver's supplies	1.05
11	6	Peter Adams Co	Lithographic paper	663.00
12	7	E. R. Bulkley, agent	Engraver's supplies	31.20
12	8	George Meier & Co	do	33.75
12	9	William D. Clark & Co	do	32.50
11	10	F. Wesel Manufacturing Co	do	172.12
11	11	James B. Lambie	do	1.50
14	12	Haislett, Nicholson & Co	do	2.10
14	13	Ernest Kübel	Electrotyping bassos	332.60
14	14	Western Union Telegraph Co	Telegrams	2.40
Dec. 31	15	The Potter Printing Press Co	1 cylinder press, etc	1,706.95
31	16	Pay roll of employees	Services, Dec., 1893	2,428.02
31	17	R. Hoe & Co	2 lithographic presses	8,325.00
1894.				
Jan. 11	1	Adams Express Co	Freight charges	.85
11	2	U. S. Express Co	do	1.95
11	3	Ernest Kübel	Electrotyping bassos	132.09
11	4	J. Baumgarten & Son	Engraver's supplies	.75
11	5	Melville Lindsay	do	2.71
11	6	George Ryneal, jr	do	4.85
11	7	do	do	1.20
12	8	R. Hoe & Co	Engraver's supplies and services	134.89
16	9	A. D. Farmer & Co	Engraver's supplies	182.28
16	10	George Meier & Co	do	35.81
19	11	L. H. Schneider's Son	Engraver's supplies, etc	106.00
17	12	Adams Express Co	Freight charges	1.95
22	13	Western Union Telegraph Co	Telegrams	.30
22	14	Charles Hellmuth	Engraver's supplies	161.50
22	15	J. E. Hurley	do	5.50
22	16	W. B. Moses & Sons	do	3.83
24	17	M. W. Beveridge	do	2.25
24	18	Peter Adams Co	Lithographic paper	230.60
25	19	George Ryneal, jr	Engraver's supplies	10.80
26	20	E. E. Jackson & Co	do	94.68
29	21	Edward Kübel	do	1.00
29	22	Robert Boyd	do	4.90
29	23	Peter Adams Co	do	199.25
29	24	do	Lithographic paper	105.60
30	25	Henry Lindenmeyr & Sons	do	84.98
31	26	Pay roll of employees	Services, Jan., 1894	897.30
31	27	do	do	1,700.49
31	28	George Meier & Co	Engraver's supplies	31.75
Feb. 5	1	Western Union Telegraph Co	Telegrams, Nov., 1893	.51

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GEOLOGICAL MAPS OF THE UNITED STATES—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1894.				
Feb. 5	2	Alfred Dolge & Son	Engraver's supplies	$17.48
5	3	Z. D. Gilman	......do	39.23
5	4	A. D. Farmer & Son Type Founding Co.	......do	45.68
7	5	Western Union Telegraph Co.	Telegrams, Dec., 1893	1.05
10	6	George Meier & Co	Lever for hand press	4.00
12	7	Peter Adams Co	Lithographic paper	1,696.20
13	8	Hanlon & Goodman	Engraver's supplies	7.00
12	9	Melville Lindsay	......do	1.30
13	10	Charles Hellmuth	......do	27.50
14	11	H. Hoffa	......do	14.10
14	12	W. C. Newton & Co	......do	18.02
24	13	A. D. Farmer & Son Type Founding Co.	......do	69.77
24	14	E. E. Jackson & Co	......do	28.60
24	15	Melville Lindsay	......do	3.13
26	16	R. Hoe & Co	Brass check nut	1.00
27	17	Peter Adams Co	Lithographic paper	683.32
28	18	Evans & Bartle	Engraving map	225.00
28	19	Pay roll of employees	Services, Feb., 1894	2,475.93
Mar. 6	1	Charles Hellmuth	Engraver's supplies	44.25
8	2	George Ryneal, jr	......do	11.65
9	3	Peter Adams Co	Lithographic paper	477.65
14	4	Charles Hellmuth	Engraver's supplies	13.75
15	5	Francis A. Finnigan	Services, Mar. 1-15, 1894	36.29
15	6	Henry J. Schaefer	Services, Nov. 30-Dec. 3, 1893	4.20
15	7	William D. Castle	Lining box with tin	6.00
17	8	Ernest Kübel	Resurfacing copper plates	31.25
17	9	Stephenson's Express	Freight charges and hauling	.90
20	10	Peter Adams Co	Lithographic paper	284.68
21	11	George W. Knox's Express	Freight charges and hauling	15.73
23	12	L. H. Schneider's Son	Engraver's supplies	9.33
23	13	Adams Express Co	Freight charges	12.95
26	14	Z. D. Gilman	Engraver's supplies	13.88
27	15	George Meier & Co	......do	11.50
27	16	L. W. Timmons	Services, Mar. 15-27, 1894	27.50
31	17	Pay roll of employees	Services, Mar., 1894	2,482.77
31	18	George Lovelace	Covering rollers	3.00
31	19	Pittsburg Reduction Co	Engraver's supplies	17.51
31	20	William Gay	......do	21.75
Apr. 10	1	George Ryneal, jr	......do	26.42
16	2	Charles G. Stott & Co	......do	363.80
19	3	E. E. Jackson & Co	......do	19.92
25	4	Charles Hellmuth	......do	17.50
25	5	Ernest Kübel	Electrotyping bassos	26.77
26	6	J. E. Hurley	Services	23.25
26	7	L. H. Schneider's Son	Engraver's supplies	3.10
30	8	Pay roll of employees	Services, Apr., 1894	1,929.91
30	9	......do	......do	351.06
May 4	1	Ernest Kübel	Resurfacing copper plates	15.62
4	2	Peter Adams Co	Lithographic paper	24.75
4	3	......do	Engraver's supplies	16.94
7	4	Z. D. Gilman	......do	.90
7	5	U. S. Express Co	Freight charges	2.30
7	6	Adams Express Co	......do	1.25
12	7	Stephenson's Express	......do	1.35
14	8	Evans & Bartle	Engraving maps	675.00
19	9	George Meier & Co	Supplies	3.00
19	10	L. H. Schneider's Son	......do	3.25
24	11	S. Oppenheimer & Bro	Stitching machine	70.00
31	12	C. & W. Pyle Co	Engraving supplies	23.27
31	13	Pay roll of employees	Services, May, 1894	2,415.80
31	14	Fred A. Schmidt	Engraving supplies	.35
June 2	1	C. B. Fenton & Co	Covering roller stocks	16.10
12	2	A. D. Farmer & Son	Engraver's supplies	4.19
14	3	S. Oppenheimer & Bro	......do	7.75
14	4	Department of the Interior	Lithographic inks	57.50
15	5	Z. D. Gilman	Engraver's supplies	19.49
25	6	......do	......do	.33
27	7	Peter Adams Co	Lithographic paper	195.24
28	8	Evans & Bartle	Engraving maps	900.00
30	9	William F. Jones	Services, June 1-14, 1894	38.40
30	10	Pay roll of employees	Services, June, 1894	2,175.10
		Total		54,743.77

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY.

JULY, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 8	1	Thomas Mason	Services, July 5-8, 1893	$5.25
8	2	Charles Lewis	Services, July 6-8, 1893	4.50
11	3	Louvenia Russell	Services, July 1-8, 1893	9.00
12	4	T. E. Williard	Services, July 1-10, 1893	19.35
17	5	Quartermaster's Department, U. S. A.	Field material	252.18
17	6	......do	......do	126.25
17	7	......do	......do	28.79
17	8	Jefferson Middleton	Traveling expenses	42.10
19	9	Charles Lewis	Services, July 10-18, 1893	12.00
19	10	Thomas Mason	......do	12.00
21	11	Quartermaster's Department, U. S. A.	Tents	37.08
21	12	......do	......do	17.00
21	13	E. J. Pullman	Geologic supplies	13.32
22	14	W. A. Pate	Topographic supplies	91.90
25	15	M. W. Beveridge	Geologic supplies	12.03
25	16	Herman Baumgarten	......do	3.50
25	17	Fred. A. Schmidt	Topographic supplies	5.40
25	18	Minnie Milligan	Services, July 6-15, 1893	14.00
27	19	Fauth & Co	Topographic supplies	62.50
27	20	Standard Typewriter Exchange	Geologic supplies	2.25
27	21	T. L. Cole	Publications	8.00
28	22	Charles Lewis	Services, July 25-27, 1893	3.75
28	23	Elijah T. Boggs	......do	4.50
28	24	W. H. Morrison's Son	Publications	16.00
31	25	C. C. Willard	Rent of office rooms, July, 1893	349.99
31	26	T. W. Stanton	Traveling expenses	63.70
31	27	......do	Services, July, 1893	117.90
31	28	L. P. Bush	......do	65.00
31	29	F. Berger	......do	80.00
31	30	Pay roll of employees	......do	589.70
31	31	......do	......do	926.30
31	32	......do	......do	805.30
31	33	......do	......do	654.00
31	34	......do	......do	151.10
31	35	......do	......do	278.00
31	36	......do	......do	817.10
31	37	......do	......do	589.10
31	38	Charles Schuchert	......do	101.10
		Total		6,390.94

AUGUST, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 4	1	Robert Beall	Publications	$10.25
4	2	Brentanos	......do	20.70
4	3	James T. White & Co	......do	8.00
4	4	N. D. C. Hodges	......do	1.00
4	5	James G. Bowen	Care and forage of public animals	11.75
4	6	James S. Topham	Topographic supplies	7.50
4	7	Richmond and Danville R. R. Co	Transportation of assistants	14.30
5	8	C. D. White	Services, July, 1893	117.90
5	9	Northern Pacific R. R. Co	Transportation of assistants	67.20
5	10	Chesapeake and Ohio R. R. Co	......do	63.60
5	11	Charles G. Stott & Co	Geologic supplies	18.23
7	12	Melville Lindsay	Laboratory supplies	4.00
7	13	Fred. A. Schmidt	Topographic supplies	12.00
7	14	George Ryneal, jr	......do	137.11
7	15	Baltimore and Ohio R. R. Co	Transportation of assistants	498.35
8	16	Fayette R. Plumb	Geologic supplies	27.60
8	17	Charles G. Stott & Co	Supplies	50.84
11	18	Chicago, Burlington and Quincy R. R.	Transportation of assistants	14.95
12	19	Lester F. Ward	Traveling expenses	120.12
14	20	E. J. Pullman	Illustration supplies	354.90
16	21	Pennsylvania R. R. Co	Transportation of property	111.60
16	22	......do	Transportation of assistants	35.25
16	23	Adams Express Co	Transportation of property	124.18
18	24	Quartermaster's Department, U. S. A.	Tents	94.69
19	25	Samuel Springman	Hauling public property	8.40

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—*Continued.*

AUGUST, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 22	26	New York Central and Hudson River R. R.	Transportation of assistants	$40.80
22	27	Atchison, Topeka and Santa Fe R. R.	do	55.49
25	28	C. Kirchhoff	Services, July 1-Aug. 19, 1893	250.00
25	29	William C. Day	do	250.00
38	30	Charles Schuchert	Traveling expenses	34.55
28	31	V. Schoonmaker	Topographic supplies	218.65
28	32	William Ballantyne & Sons	Publications	3.20
28	33	Charles G. Stott & Co	Topographic supplies	12.48
28	34	Haislett, Nicholson & Co	Geologic supplies	4.00
30	35	Queen & Co., Incorporated	Topographic supplies	60.00
30	36	Gulf, Colorado and Santa Fe R. R.	Transportation of assistants	11.35
31	37	F. Berger	Services, Aug., 1893	80.00
31	38	L. P. Bush	do	65.00
31	39	Charles Schuchert	do	101.10
31	40	C. D. White	do	117.90
31	41	T. W. Stanton	do	117.90
31	42	Pay roll of employees	do	589.70
31	43	do	do	884.13
31	44	do	do	795.50
31	45	do	do	661.54
31	46	do	do	151.10
31	47	do	do	278.00
31	48	do	do	817.00
31	49	do	do	589.10
31	50	C. C. Willard	Rent of office rooms, Aug., 1893	349.99
		Total		8,473.00

SEPTEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 15	1	Fred A. Schmidt	Topographic supplies	$5.10
15	2	S. Springman	Hauling public property	1.50
15	3	Stephenson's Express	Freight charges and hauling	3.75
15	4	do	do	4.15
15	5	John C. Parker	Topographic supplies	2.50
15	6	William M. Fontaine	Traveling expenses	6.05
19	7	Charles Schuchert	do	46.51
19	8	Pennsylvania R. R. Co	Transportation of assistants	28.20
19	9	Northern Pacific R. R. Co	do	7.00
19	10	Chicago and Northwestern R. R. Co.	do	18.50
19	11	Southern Pacific Co	do	18.35
19	12	National Express Co	Transportation of property	36.57
19	13	George Ryneal, jr	Supplies	101.90
25	14	Atchison, Topeka and Santa Fe Ry. Co.	Transportation of assistants	18.00
25	15	U. S. Express Co	Freight charges	9.15
26	16	Lester F. Ward	Traveling expenses	107.55
28	17	Burlington and Missouri River R. R. in Nebraska.	Transportation of assistants	8.82
30	18	Northern Pacific R. R. Co	do	33.00
30	19	Wisconsin Central lines	do	8.00
30	20	T. W. Stanton	Services, Sept., 1893	114.20
30	21	Pay roll of employees	do	570.60
30	22	do	do	911.20
30	23	do	do	681.60
30	24	do	do	618.47
30	25	do	do	147.80
30	26	do	do	269.00
30	27	do	do	790.80
30	28	do	do	571.80
30	29	L. P. Bush	do	65.00
30	30	Charles Schuchert	do	97.80
		Total		5,302.87

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

OCTOBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 4	1	Robert Beall	Publications	$25.00
9	2	C. C. Willard	Rent of offices, Sept., 1893	349.99
9	3	Columbia Phonograph Co	Rent of phonographs	42.50
9	4	Fauth & Co	Repairing heliotrope	7.50
9	5	F. Berger	Services, Sept., 1893	80.00
9	6	Northern Pacific R. R. Co	Transportation of assistants	22.00
9	7	Gulf, Colorado and Santa Fe R. R. Co.	Transportation of property	100.71
9	8	Stephenson's Express	do	14.78
10	9	Adams Express Co	do	10.35
10	10	do	do	28.95
11	11	Chicago and Northwestern R. R. Co.	Transportation of assistants	30.80
12	12	Robert Beall	Publications	39.50
12	13	Minnie Milligan	Services, July 26-31, 1893	10.00
12	14	do	Services, Sept. 2-30, 1893	50.00
13	15	E. J. Pullman	Geologic supplies	5.20
13	16	Gottlieb Spitzer	Geologic supplies and repairs	2.00
13	17	Chicago, St. Paul, Minneapolis and Omaha Ry.	Transportation of assistants	22.10
13	18	Chicago, Burlington and Quincy R. R.	do	22.50
13	19	Baltimore and Ohio R. R. Co	do	16.50
13	20	do	do	426.55
16	21	Edward Kübel	Repairs to instruments	364.50
16	22	F. A. Lucas	Traveling expenses	7.85
18	23	Devereux & Gaghan	Repairs to photographic tank	11.00
18	24	George W. Knox's Express	Freight charges and hauling	22.51
18	25	Charles Schuchert	Traveling expenses	118.87
25	26	Henry Bufford	Services, Oct. 2-12, 1893	20.00
25	27	Eugene Leamy	Services, July 1-Aug. 31, 1893	75.00
25	28	C. Kirchhoff	Services, Aug. 21-Oct. 14, 1893	350.00
25	29	Atchison, Topeka and Santa Fe Ry.	Transportation of assistant	51.75
25	30	Southern Pacific Co	Transportation of property	31.15
25	31	Henry H. Bennett	Photographic views	6.00
26	32	U. S. Express Co	Freight	5.00
27	33	do	do	.85
30	34	Wabash Railroad Co	Transportation of assistant	9.50
30	35	Burlington and Missouri River R. R. in Nebraska.	do	6.17
30	36	Sackett & Wilhelms	Illustrations	20.00
30	37	Kirk & Bailey	Geologic supplies	4.00
31	38	James E. Skinner	Services, Oct. 27, 1893	.75
31	39	C. C. Willard	Rent of office rooms, Oct., 1893	349.99
31	40	T. W. Stanton	Services, Oct., 1893	117.90
31	41	C. D. White	Services, Sept. and Oct., 1893	232.10
31	42	L. P. Bush	Services, Oct., 1893	65.00
31	43	F. Berger	do	80.00
31	44	Pay roll of employees	do	589.70
31	45	do	do	936.90
31	46	do	do	704.20
31	47	do	do	599.10
31	48	do	do	252.20
31	49	do	do	278.00
31	50	do	do	785.32
31	51	do	do	589.10
		Total		7,991.34

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

NOVEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Nov. 2	1	J. W. Powell	Traveling expenses	$32.25
2	2	......do	......do	32.45
2	3	P. C. Warman	......do	41.75
2	4	......do	......do	33.10
6	5	Robert Beall	Publications	28.75
7	6	Fred. A. Schmidt	Topographic supplies	5.10
7	7	Z. D. Gilman	Laboratory supplies	15.02
7	8	George W. Plumley Co	Geologic supplies	33.75
7	9	National Press Intelligence Co	Publications	14.00
7	10	Duluth, South Shore and Atlantic Ry. Co.	Transportation of assistants	39.25
7	11	Chicago, Burlington and Quincy Ry.	......do	21.75
8	12	Southern California Ry. Co	......do	45.00
8	13	Robert Clarke & Co	Publications	7.75
11	14	The Review of Reviews Co	......do	4.75
11	15	Herman Baumgarten	Topographic supplies	4.00
11	16	E. J. Pullman	Illustration supplies	86.18
11	17	E. E. Jackson & Co	......do	31.00
11	18	Geo. W. Knox's Express	Freight charges and hauling	159.79
16	19	Gottlieb Spitzer	Geologic supplies	3.50
16	20	John C Parker	Topographic supplies	5.55
16	21	U. S. Express Co	Freight charges	120.20
17	22	Eimer & Amend	Laboratory supplies	4.80
17	23	Fayette R. Plumb	Geologic supplies	15.65
17	24	Office Specialty Manufacturing Co.	Topographic supplies	2.50
17	25	Haislett, Nicholson & Co	......do	5.00
17	26	......do	......do	27.40
17	27	Stephenson's Express	Freight charges and hauling	17.75
18	28	T. W. Stanton	Traveling expenses	54.35
21	29	Robert Beall	Publications	89.05
21	30	John C. Parker	Geologic supplies	.50
21	31	......do	Eyelets	.25
21	32	W. H. Morrison's Son	Publications	16.00
21	33	Standard Typewriter Exchange	Geologic supplies	5.00
21	34	Chicago and Alton Railroad	Transportation of assistants	46.16
21	35	Chicago, Milwaukee and St. Paul Ry.	......do	20.74
21	36	Chicago and Northwestern R. R. Co.	......do	70.15
21	37	Burlington and Missouri River R. R. in Nebraska.	......do	45.35
22	38	David T. Day	Traveling expenses	91.05
24	39	C. D. White	......do	15.70
24	40	......do	......do	44.31
24	41	Charles D. Walcott	......do	95.42
24	42	Fremont, Elkhorn and Missouri Valley R. R.	Transportation of assistants	26.55
24	43	St. Louis and San Francisco R. R. Co.	......do	11.52
28	44	E. W. Parker	Traveling expenses	63.50
28	45	Charles Schuchert	......do	31.93
28	46	Minnie Milligan	Services, Oct. 2–31, 1893	52.00
28	47	A. P. Fish	Services, Oct., 1893	30.00
29	48	Jane L. Ware	Services, Nov. 1–15, 1893	7.34
30	49	Pay roll of employees	Services, Nov., 1893	570.60
30	50	......do	......do	903.86
30	51	......do	......do	681.60
30	52	......do	......do	581.80
30	53	......do	......do	474.00
30	54	......do	......do	269.00
30	55	......do	......do	790.80
30	56	......do	......do	571.80
30	57	F. Berger	......do	80.00
30	58	L. P. Bush	......do	65.00
30	59	H. Gibb	Services, Sept. 16–30, 1893	40.00
30	60	C. C. Willard	Rent of office rooms, Nov. 1893	349.99
		Total		7,033.31

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

DECEMBER, 1893.

Date of payment.	No of voucher.	To whom paid.	For what paid.	Amount.
Dec 6	1	Hally Ballinger Bryan	Services, Nov., 1893	$25.00
6	2	Z. D. Gilman	Supplies	263.06
9	3	J. E. Hurley	Geological boring machine	3.00
9	4	C. Schneider	Services (job)	1.50
9	5	M. S. Mitchell	Services, Oct. 9-21, 1893	23.50
9	6	Henry Bufford	Services, Oct. 13-Nov. 10, 1893	50.00
9	7	Denver and Rio Grande R. R. Co.	Transportation of property	1.28
9	8	Chicago, Burlington and Quincy R. R.	Transportation of assistants	33.47
9	9	Southern Pacific Co	do	64.50
11	10	Mayer & Muller	Publications	126.02
11	11	Citizens' National Bank	Bill of exchange	1.72
11	12	Chicago, Milwaukee and St. Paul Ry.	Transportation of assistants	86.11
11	13	Denver and Rio Grande Ry	do	7.12
12	14	E. E. Jackson & Co	Geologic supplies	24.75
12	15	Belt & Dyer	do	9.00
14	16	Office Specialty Manufacturing Co.	do	140.00
14	17	E. J. Lewis	Paleontologic supplies	2.25
14	18	Library Bureau	Topographic supplies	7.20
14	19	Western Union Telegraph Co	Telegrams	57.38
14	20	William H. Dall	Traveling expenses	41.33
16	21	David T. Day	do	17.87
16	22	John Moore	Publications	30.00
18	23	Stephenson's Express	Freight charges	19.86
18	24	Pennsylvania Co.	Transportation of assistants	17.50
18	25	do	do	17.50
18	26	Chicago and Northwestern R. R. Co.	do	16.99
18	27	Jos. D. Weeks	Services, July 1-Sept. 30, 1893	550.00
19	28	Ch. Ganlon	Publications	171.39
19	29	do	do	63.42
19	30	Citizens' National Bank	Bill of exchange	1.99
19	31	W. C. Day	Services, Aug. 21-Sept. 15, 1893	100.00
19	32	Southern California Ry	Transportation of assistants	67.00
20	33	Lake Shore and Michigan Southern Ry.	do	34.52
20	34	do	do	22.00
20	35	James M. Swank	Services, July 1-Sept. 30, 1893	300.00
20	36	Minnie Milligan	Services, Nov., 1893	46.00
21	37	John C. Parker	Publications	111.00
21	38	Baltimore and Ohio R. R. Co	Transportation of assistant	17.50
22	39	The Johns Hopkins Press	Publications	8.50
23	40	John Birkinbine	Services, July 1-Sept. 15, 1893	275.00
27	41	J. H. Langille	Publications	2.00
27	42	E. W. Parker	Traveling expenses	10.10
27	43	Colorado Midland Ry	Transportation of assistants	15.00
27	44	Atchison, Topeka and Santa Fe Ry.	do	126.35
29	45	James T. White	Publications	8.00
31	46	C. C. Willard	Rent of office rooms, Dec., 1893	349.99
31	47	Spencer B. Newberry	Services, July, 1893	50.00
31	48	F. Berger	Services, Dec., 1893	80.00
31	49	L. P. Busch	do	65.00
31	50	Pay roll of employees	do	589.70
31	51	do	do	1,036.90
31	52	do	do	704.20
31	53	do	do	599.10
31	54	do	do	488.00
31	55	do	do	278.00
31	56	do	do	817.10
31	57	do	do	702 14
31	58	Mary C. Mahon	Services, Dec. 4-30, 1893	33.00
31	59	Enos Wilson	Services, Dec. 5-9, 1893	9.00
		Total		8,819.81

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

JANUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Jan. 3	1	Robert Beall	Publications	$111.00
9	2	......do	......do	25.00
11	3	Adams Express Co	Freight charges	125.90
11	4	U. S. Express Co	......do	79.85
11	5	National Press Intelligence Co	Publications	9.95
11	6	R. R. Bowker	......do	5.00
11	7	Thomas W. Smith	Map cases	79.20
11	8	Columbia Phonograph Co	Rent of phonographs	42.50
11	9	M. Milligan	Services, Dec., 1893	49.00
11	10	Pennsylvania R. R. Co	Transportation of property	7.20
11	11	......do	Transportation of assistants	21.00
11	12	Vandalia Line	......do	40.50
11	13	Burlington and Missouri River Railroad in Nebraska.	......do	51.45
11	14	Herman Baumgarten	Rubber stamp, etc	1.50
11	15	George Ryneal, jr	Supplies	86.09
11	16	......do	......do	34.80
12	17	William Whipple	Services, Nov., 1893	35.00
13	18	D. T. Day	Traveling expenses	28.90
15	19	Woodward & Lothrop	Topographic supplies	14.62
15	20	Herman Baumgarten	Supplies	6.50
15	21	Fred. A. Schmidt	......do	9.60
15	22	St. Paul and Duluth R. R. Co	Transportation of assistants	25.50
16	23	Samuel Springman	Hauling specimens	2.44
19	24	L. H. Schneider's Son	Topographic supplies	1.00
19	25	......do	Laboratory supplies	3.40
17	26	Adams Express Co	Freight charges	108.10
22	27	The Standard Engraving Co	Mineral resource supplies	3.00
22	28	W. B. Moses & Sons	Illustration supplies	9.00
22	29	Wagner Free Institute of Science	Publications	7.00
22	30	John C. Parker	Supplies	3.75
22	31	Pennsylvania R. R. Co	Freight charges	29.69
22	32	Western Union Telegraph Co	Telegrams	7.57
24	33	John C. Parker	Laboratory supplies	20.50
24	34	J. B. Chamberlain	Geologic supplies	8.45
24	35	E. Norris	Publications	5.50
25	36	George Ryneal, jr	Supplies	56.83
26	37	E. J. Pullman	......do	183.64
26	38	E. E. Jackson & Co	......do	57.75
29	39	Edward Kübel	Repairs to instruments	15.00
31	40	Pay roll of employees	Services, Jan., 1894	602.70
31	41	......do	......do	1,068.00
31	42	......do	......do	719.90
31	43	......do	......do	611.50
31	44	......do	......do	647.14
31	45	......do	......do	334.20
31	46	......do	......do	835.20
31	47	......do	......do	688.90
31	48	F. Berger	......do	80.00
31	49	L. P. Bush	......do	65.00
31	50	Eimer & Amend	Laboratory supplies	5.75
31	51	Office Specialty Manufacturing Co.	Geologic supplies	1.92
31	52	C. C. Willard	Rent of office rooms, Jan. 1894	349.99
31	53	Herman Baumgarten	Geologic supplies	3.00
31	54	M. Milligan	Services, Jan., 1894	52.00
		Total		7,477.90

FEBRUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Feb. 3	1	J. M. Springman	Forage of public animals	$18.00
5	2	Western Union Telegraph Co	Telegrams, Nov., 1893	13.69
5	3	Z. D. Gilman	Supplies	124.25
5	4	V. Essex	Services, Jan. 18-31, 1894	24.00
5	5	A. E. Balloch	Services, Dec. 16, 1893-Jan. 15, 1894	32.00
5	6	Jas. D. and E. S. Dana	Publications	6.00
7	7	Robert Beall	......do	50.35
7	8	Atchison, Topeka and Santa Fe Ry.	Transportation of assistants	32.45
7	9	David T. Day	Traveling expenses	27.20
7	10	Western Union Telegraph Co	Telegrams, Dec., 1893	1.73

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

NERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

FEBRUARY, 1894—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Feb. 8	11	William C. Douglas	Services, Jan. 26–Feb. 7, 1894	$11.00
8	12	Melville Lindsay	Illustration supplies	1.20
8	13	John C. Parker	Topographic supplies	6.00
10	14	Henry S. Williams	Services	150.00
10	15	E. J. Pullman	Geological supplies	12.50
10	16	N. A. Poole	Illustration supplies	1.40
10	17	Melville Lindsay	do	2.34
10	18	E. J. Lewis	Paleontologic supplies	1.00
12	19	Chas. G. Stott & Co	Supplies	12.15
13	20	John C. Entriken	Laboratory repairs	2.60
13	21	The Pennsylvania R. R. Co	Transportation of assistants	21.00
13	22	Robert E. Lee Grigsby	Services, Feb. 7–9, 1894	5.35
13	23	A. C. Peale	Services, Feb. 8–9, 1894	12.00
14	24	Chas. G. Stott & Co	Geologic supplies	7.50
14	25	John C. Parker	Mineral resource supplies	1.75
14	26	Pennsylvania Co	Transportation of assistants	35.00
24	27	Southern California R. R. Co	do	57.00
24	28	Northern Pacific R. R. Co	do	153.82
24	29	Pennsylvania R. R. Co	Transportation of property	5.18
24	30	Devereux & Gaghan	Illustration repairs	11.00
24	31	Wm. D. Clark & Co	Topographic supplies	11.63
24	32	Wyckoff, Seamans & Benedict	Geologic supplies	7.00
24	33	L. Feuchtwanger & Co	Laboratory supplies	9.50
24	34	E. E. Jackson & Co	Supplies	50.84
26	35	George Ryneal, jr	Geologic supplies	8.68
26	36	S. E. Cassino	Publications	5.00
26	37	O. A. Stevens	do	4.00
26	38	R. R. Bowker	do	3.50
26	39	International Manufacturers' Express Agency.	Services and material	2.50
26	40	F. Berger	Services, Feb., 1894	80.00
26	41	L. P. Bush	do	65.00
26	42	Pay roll of employees	do	544.60
26	43	do	do	974.80
26	44	do	do	650.20
26	45	do	do	557.00
26	46	do	do	576.72
26	47	do	do	321.60
26	48	do	do	754.60
26	49	do	do	622.20
26	50	C. C. Willard	Rent of office rooms, Feb., 1894	349.99
26	51	Northern Pacific R. R. Co	Transportation of property	26.23
26	52	East Tennessee, Virginia and Georgia R. R.	Transportation of assistants	16.50
26	53	Robert Beall	Publications	62.95
		Total		6,544.50

MARCH, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Mar. 6	1	Baker & Adamson	Laboratory supplies	$7.90
2	2	George R. Seiffert	Topographic supplies	2.50
5	3	W. H. Morrison's Son	Publications	12.20
8	4	Herman Baumgarten	Geologic supplies	3.60
8	5	Thomas Somerville & Sons	Illustration supplies	5.10
8	6	George Ryneal, jr	Supplies	89.84
8	7	Gustav E. Stechert	Publications	338.89
8	8	Pennsylvania R. R. Co	Transportation of property	1.40
9	9	Chas. G. Stott & Co	Topographic supplies	12.48
14	10	Melville Lindsay	do	1.76
15	11	T. E. Williard	Services, March 1–15, 1894	24.19
15	12	Chicago, Rock Island and Pacific R. R.	Transportation of assistants	129.50
15	13	Western Union Telegraph Co	Telegrams, Dec., 1893	.23
15	14	do	Telegrams, Jan., 1894	1.66
17	15	Stephenson's Express	Freight charges and hauling	5.13
17	16	Chas. G. Stott & Co	Topographic supplies	38.94
17	17	Lansburgh & Bro	do	35.40
17	18	John C. Parker	Geologic supplies	1.25
17	19	M. Milligan	Services, Feb. 15–Mar. 15, 1894	43.00
17	20	A. H. Storer	Publications for mineral resources	9.00
17	21	Nevada, California, and Oregon Ry. Co.	Transportation of property	1.17
21	22	E. W. Parker	Traveling expenses	66.15
21	23	George W. Knox's Express	Freight charges and hauling	22.52

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

MARCH, 1894—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
23	24	W. Zinsser & Co	Geologic supplies	$5.50
23	25	L. H. Schneider's Son	Supplies	3.45
23	26	Adams Express Co	Freight charges	68.45
24	27	Andrew Renz	Dressing geological hammer	.50
24	28	Thomas W. Smith	Supplies	73.50
26	29	Smithsonian Institution	Transportation of exchanges	298.17
26	30	Z. D. Gilman	Supplies	144.11
27	31	Koch Sons & Co	do	2.75
27	32	W. H. Morrison's Son	Publications	16.00
29	33	William F. Porter	do	7.00
29	34	A. C. Peale	Services	75.00
29	35	Atchison, Topeka and Santa Fe Ry.	Freight	28.18
29	36	Colorado Midland Ry	do	2.32
31	37	F. Berger	Services, Mar., 1894	80.00
31	38	L. P. Bush	do	65.00
31	39	Richmond and Danville R. R.	Transportation of assistant	17.50
31	40	Pay roll of employees	Services, Mar., 1894	602.70
31	41	do	do	1,055.10
31	42	do	do	719.90
31	43	do	do	611.50
31	44	do	do	497.80
31	45	do	do	335.90
31	46	do	do	835.20
31	47	do	do	688.90
31	48	C. C. Willard	Rent of office rooms, Mar., 1894	349.99
31	49	Robert Beall	Publications	77.20
		Total		7,515.43

APRIL, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Apr. 10	1	John Birkinbine	Services, Nov. 1, 1893–Feb. 28, 1894	$400.00
10	2	George F. Kunz	Services, Feb. 1–Mar. 15, 1894	110.00
10	3	A. C. Peale	Services, Mar. 16–31, 1894	25.00
10	4	Columbia Phonograph Co	Rent of phonographs	42.50
10	5	Western Union Telegraph Co	Telegrams, Feb., 1894	1.00
10	6	E. J. Pullman	Supplies	85.95
10	7	George Ryneal, jr	do	59.70
10	8	E. W. Parker	Traveling expenses	29.93
16	9	Pennsylvania R. R. Co	Transportation of assistant	8.00
16	10	Central Railroad and Banking Co. of Georgia.	do	7.23
19	11	Fred. A. Schmidt	Supplies	19.36
19	12	F. E. Jackson & Co	do	78.00
19	13	Charles G. Stott & Co	do	1.50
25	14	William A. Raborg	Traveling expenses	32.00
26	15	Pennsylvania R. R. Co	Freight charges	7.75
26	16	J. E. Hurley	Geologic repairs	1.50
26	17	Smith Premier Typewriter Co	Geologic supplies	1.00
26	18	L. H. Schneider's Son	Supplies	.50
28	19	Ohio and Mississippi R. R. Co	Transportation of assistant	17.00
28	20	National Press Intelligence Co	Publications	12.70
28	21	B. Westermann & Co	do	4.75
28	22	Brentanos	do	22.80
28	23	John C. Parker	Mineral resource supplies	118 00
28	24	David T. Day	Traveling expenses	79.50
30	25	Jefferson Middleton	do	65 85
30	26	M. Milligan	Services, Mar. 16–Apr. 6, 1894	46.25
30	27	C. C. Willard	Rent of office rooms, Apr., 1894	349.99
30	28	C. D. White	Services, Apr., 1894	115.40
30	29	Pay roll of employees	do	576.85
30	30	do	do	1,019.20
30	31	do	do	688.90
30	32	do	do	587.40
30	33	do	do	363.20
30	34	do	do	436.90
30	35	do	do	799.40
30	36	do	do	543.95
30	37	F. Berger	do	80.00
30	38	L P. Bush	do	65.00
30	39	Sydenham Torbert	Services, Feb. 1–Apr. 5, 1894	61.00
		Total		6,964.96

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

MAY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
May 4	1	Titus Ulke	Services, Mar. 24–Apr. 9, 1894	$75.00
4	2	Charles H. Cherry	Services, Mar. 26–Apr. 9, 1894	22.50
4	3	Chesapeake and Ohio R. R. Co	Transportation of assistant	19.50
4	4	Edward Kübel	Supplies and repairs	143.45
5	5	The Northern Distillery	Geologic supplies	21.25
7	6	Z. D. Gilman	Supplies	173.49
7	7	Western Union Telegraph Co	Telegrams, Mar., 1894	8.48
7	8	U. S. Express Co	Freight charges	22.55
8	9	T. Hudson Willis	Services, Mar. 26–Apr. 7, 1894	25.00
7	10	Adams Express Co	Freight charges	43.10
11	11	Mellville Lindsay	Illustration supplies	1.50
11	12	E. J. Pullman	do	2.75
11	13	Cutter & Wood	Geologic supplies	14.75
12	14	Stephenson's Express	Freight charges and hauling	5.11
16	15	Pennsylvania R. R Co	Transportation of assistant	9.24
19	16	N. D. C. Hodges	Mineral resource supplies	5.50
19	17	George N. Rider	Publications	6.00
19	18	L. H. Schneider's Son	Illustration supplies	.50
19	19	John C. Parker	Geologic supplies	1.85
19	20	Theodore H. Johnson	Services, Feb. 24–Apr. 9, 1894	95.00
19	21	Thomas Somerville & Sons	Topographic repairs	11.65
19	22	Eimer & Amend	Laboratory supplies	5.30
22	23	E. E. Jackson & Co	Illustration supplies	23.70
22	24	F. W. Clarke	Traveling expenses	15.30
21	25	E. J. Pullman	Repairs and supplies	8.50
21	26	Z. D. Gilman	Supplies	132.56
25	27	William Kerr	Geologic supplies	8.00
31	28	John C. Parker	do	55.00
31	29	Herman Baumgarten	Mineral resource supplies	.75
31	30	Baltimore and Ohio R. R. Co	Transportation of assistant	17.75
31	31	C. D. White	Services, May, 1894	119.20
31	32	F. Berger	do	80.00
31	33	L. P. Bush	do	65.00
31	34	C. C. Willard	Rent of office rooms, May, 1894	349.99
31	35	Pay roll of employees	Services, May, 1894	596.30
31	36	do	do	1,392.00
31	37	do	do	579.20
31	38	do	do	442.80
31	39	do	do	323.60
31	40	do	do	451 20
31	41	do	do	826.20
31	42	do	do	562.10
		Total		6,762.62

JUNE, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 4	1	David T. Day	Traveling expenses	$19.45
13	2	Northern Pacific R. R. Co	Transportation of property	7.42
13	3	Pennsylvania R. R. Co	do	.72
13	4	William Kerr	Geologic supplies	24.00
14	5	Photo-Engraving Co	Illustration supplies	6.50
14	6	J. Karr	Topographic repairs	18.00
14	7	E. J. Pullman	Supplies	170.15
14	8	Charles E. Munroe	Analyses of 20 rocks	168.00
14	9	Western Union Telegraph Co	Telegrams, July, August, and September, 1893.	3.47
14	10	do	Telegrams, Apr., 1894	15.58
14	11	Department of the Interior	Illustration supplies	294.85
14	12	Franklin & Co	Geologic supplies	.75
15	13	E. W. Parker	Traveling expenses	12.30
15	14	Department of the Interior	Topographic supplies	6.15
15	15	do	do	64.40
15	16	do	Mineral resource supplies	6.00
15	17	Z. D. Gilman	Laboratory supplies	11.98
18	18	Cutter & Wood	Geologic supplies	28.56
19	19	Abraham Lisner	Topographic supplies	10.40
19	20	Baltimore and Ohio R. R. Co	Transportation of assistant	11.00
25	21	H C. Hunter	Original drawings	126.00
25	22	E. J. Pullman	Illustration supplies	98.50
25	23	Z. D. Gilman	Supplies	259.57

Abstract of disbursements made by John D. McChesney, chief disbursing clerk, U. S. Geological Survey—Continued.

GENERAL EXPENSES OF THE GEOLOGICAL SURVEY—Continued.

JUNE, 1894—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 24	24	Thos. W. Smith	Illustration supplies	$12.25
27	25	C. E. Munroe	Analyses of phosphates	75.00
27	26	Baltimore and Ohio R. R. Co	Transportation of assistant	39.25
27	27	C. D. White	Traveling expenses	34.91
30	28	W. F. Roberts	Remodeling typewriter	53.50
30	29	Theodore Johnson	Services, Apr. 20–June 14, 1894	112.50
30	30	C. E. Munroe	Analyses of specimens	15.00
30	31	Lester F. Ward	Traveling expenses	42.30
30	32	L. P. Bush	Services, June, 1894	65.00
30	33	Titus Ulke	Services, Feb. 1–Mar. 6, 1894	75.00
30	34	Pittsburg, Cincinnati, Chicago and St. Louis Ry.	Transportation of assistant	18.85
30	35	Pay roll of employees	Services, June, 1894	576.85
30	36	do	do	1,820.70
30	37	do	do	560.40
30	38	do	do	428.60
30	39	do	do	428.60
30	40	do	do	387.40
30	41	do	do	799.40
30	42	do	do	543.95
30	43	Elizabeth A. Balloch	Services, June 5–27, 1894	50.00
30	44	Lutz & Bro	Geologic supplies	50.00
30	45	Columbia Phonograph Co	Rent of phonographs	42.50
30	46	C. C. Willard	Rent of office rooms, June, 1894	349.99
30	47	Joseph F. Page	Geologic supplies	20.60
		Total		7,966.30

Abstract of disbursements made by J. S. Diller, special disbursing agent, U. S. Geological Survey, during fiscal year 1893–'94.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
1893.				
July 24	1	Andrew Miller	Subsistence	$15.00
Aug. 1	2	James Storrs	Services, July, 1893	60.00
3	3	L. A. Miller	Field expenses	19.50
9	4	L. W. Bunnell	do	20.00
15	5	L. A. Miller	do	3.00
16	6	L. M. Kaiser	do	18.00
16	7	P. P. Hudson	do	15.85
20	8	Thompson & Kellogg	do	6.25
29	9	J. C. Young	do	12.30
Sept. 1	10	F. B. Hooselkus	do	15.50
2	11	L. M. Kaiser	do	15.25
4	12	Andrew Miller	do	10.50
6	13	William Hooper	do	6.50
7	14	P. Reichling	do	6.00
7	15	James Storrs	Services, Aug., 1893	60.00
11	16	J. S. Diller	Traveling expenses	112.80
12	17	Charles Tait	Field expenses	19.15
28	18	Bass & Dunning	do	14.87
Oct. 1	19	H. Clineschmidt	do	7.50
2	20	John Gleason	do	3.50
3	21	James Regan	do	4.25
5	22	W. McCormick	do	9.00
10	23	G. Stephenson	do	20.00
16	24	G. M. Lowry	do	26.88
18	25	J. S. Diller	do	95.19
18	26	James Storrs	Services, Sept., 1893	60.00
19	27	J. B. James	Field expenses	15.50
24	28	Palace Hotel	do	8.00
31	29	James Storrs	Services, Oct., 1893	60.00
Nov. 8	30	J. S. Diller	Traveling expenses	99.10
8	31	do	Field expenses	157.95
Dec. 5	32	James Storrs	do	97.87
5	33	do	Services, Nov., 1893	54.00
1894.				
Jan. 4	34	J. S. Diller	Field expenses	60.00
31	35	J. F. Bradley	do	11.00
		Total		1,220.21

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey, during fiscal year 1893-'94.

JULY, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 12	1	Hardrader & White	1 horse	$100.00
12	2	M. R. Campbell	Traveling expenses	30.50
12	3	W. C. Mendenhall	do	21.10
12	4	J. E. Wolff	do	9.20
12	5	do	Field expenses	6.10
17	6	V. Schoonmaker	Buckboard	107.00
19	7	C. Willard Hayes	Traveling expenses	36.15
19	8	W. Lindgren	do	63.75
19	9	Arnold Hague	do	17.25
19	10	T. A. Jaggar, jr	do	46.25
19	11	Thomas Parry	do	5.79
19	12	Cyrus C. Babb	do	24.25
19	13	Frank Hollister	do	31.05
19	14	H. W. Turner	do	42.25
19	15	T. Nelson Dale	do	39.39
19	16	do	Field expenses	4.17
19	17	T J. Morrison	Field supplies	63.40
20	18	John R. Biering	Pasturage	22.00
20	19	do	1 horse	70.00
20	20	H. C. Ballard	1 horse	100.00
20	21	Fred. A. Fielding	1 horse	65.00
20	22	G. W. Sinder	2 mules	225.00
20	23	Harmon Cleaveland	1 mule	80.00
20	24	J. L. Oakes	3 animals	275.00
21	25	William B. Lloyd	Supplies	172.20
21	26	Highsmith & Winter	Shoeing, etc	27.55
21	27	G. K. Gilbert	Traveling expenses	30.75
21	28	do	do	26.00
22	29	Robert T. Hill	do	9.00
25	30	Oscar Toss	Photographic supplies	13.90
25	31	Geo. H. Eldridge	Traveling expenses	39.47
25	32	Otto Ketelsen	Supplies	91.90
25	33	J. H. Conrad & Co	do	38.58
25	34	Geo. H. Eldridge	Field expenses	89.45
25	35	C. Willard Hayes	do	66.13
29	36	A. T. Elliott	Hauling	2.50
29	37	James Forristell	Supplies	9.10
29	38	Walter H. Weed	Traveling expenses	38.10
29	39	Louis V. Pirrson	do	63.35
31	40	William Hallock	Services, July 1-27, 1893	100.00
31	41	George H. Eldridge	Services, July, 1893	255.91
31	42	Bailey Willis	do	251.04
31	43	Arnold Hague	do	337.00
31	44	G. K. Gilbert	do	337.00
31	45	N. H. Darton	do	134.80
31	46	T. Nelson Dale	do	168.50
31	47	Louis M. Prindle	do	40.32
31	48	H. W. Turner	do	151.60
31	49	S. C. Chaney	do	50.00
31	50	E. H. Shuster	do	101.10
31	51	J. S. Diller	do	202.20
31	52	Walter H. Weed	do	151.60
31	53	W. Lindgren	do	151.60
31	54	Pay roll of employees	do	955.30
31	55	do	do	306.81
31	56	do	do	273.01
31	57	C. R. Van Hise	do	260.00
31	58	C. Whitman Cross	do	168.50
31	59	J. E. Wolff	do	120.00
31	60	H. F. Phillips	do	60.00
31	61	C. Willard Hayes	Field expenses	213.85
31	62	Whitman Saddle Co	Saddle, etc	64.50
		Total		7,027.22

AUGUST, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 2	1	Arthur Keith	Traveling expenses	$41.10
2	2	C. Ellet Cabell	do	20.05
2	3	Isaac Munroe	do	18.80
2	4	Pay roll of employees	Services, July, 1893	152.26
2	5	Charles Perry	do	52.26
2	6	James Deagon	do	43.55
2	7	W. S. Bayley	do	130 00
2	8	J. M. Clements	do	104.00

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

AUGUST, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 2	9	Charles Oley	Services, July, 1893	$75.00
2	10	J. B. Woodworth	do	50.00
2	11	J. Stanley-Brown	do	136.96
3	12	Louis M. Prindle	Traveling expenses	22.86
3	13	R. E. Dodge	Services, July, 1893	40.00
3	14	William B. Clark	do	50.00
3	15	Ben. K. Emerson	do	130.00
4	16	Charles D. Walcott	Traveling expenses	17.63
4	17	W. H. Frith	Services, July, 1893	44.51
4	18	A. J. Steele	do	46.45
4	19	Pay roll of employees	do	232.90
4	20	M. R. Campbell	Field expenses	257.11
5	21	G. K. Gilbert	do	131.29
5	22	do	do	15.81
5	23	do	do	51.93
5	24	John A. Udden	Services, July, 1893	95.00
5	25	L. V. McQuiston	do	30.19
5	26	S. W. Whittaker	do	50.00
5	27	E. B. Mathews	do	60.00
5	28	do	Traveling expenses	64.00
5	29	C. Whitman Cross	do	65.65
5	30	U. Laughlin	Supplies	14.95
5	31	Pittsburg and Lake Superior Iron Co.	do	9.73
5	32	do	Subsistence	28.02
8	33	G. K. Gilbert	Field expenses	14.55
8	34	W. S. Wilson	Services, July, 1893	60.00
11	35	John Hart	do	60.97
11	36	W. H. Utterback	do	30.62
11	37	J. E. Wolff	Traveling expenses	42.45
11	38	W. Lindgren	Supplies	34.78
11	39	do	do	40.34
11	40	Goldberg, Bowen & Lebenbaum	do	45.10
11	41	Highsmith & Winter	Shoeing, etc	24.50
11	42	H. W. Turner	Field expenses	86.17
11	43	W. Lindgren	do	68 50
12	44	R. E. Dodge	Traveling expenses	34.44
12	45	Yeger-Talmage Mercantile Co	Supplies	17.56
14	46	Chassell & Quick	Board and lodging	11.08
14	47	Charles S. Prosser	Services, July 17-31, 1893	52.00
15	48	J. B. Woodworth	Traveling expenses	30.73
15	49	T. Nelson Dale	do	48.77
15	50	Louis M. Prindle	do	20.87
28	51	G. K. Gilbert	Field expenses	61.05
28	52	do	do	11.30
28	53	do	do	4.45
28	54	do	do	30.89
30	55	Frank L. Benepe	Field supplies	28.00
30	56	William Foden	Supplies	74.78
30	57	J. B. Woodworth	Traveling expenses	30.64
30	58	W. A. Brent	Forage	3.49
30	59	Frank Sharon	Hire of team	19.50
30	60	A. T. Elliott	Hauling	7.50
30	61	W. S. Bayley	Traveling expenses	53 51
30	62	Walter H. Weed	Field expenses	22.20
30	63	Arthur Keith	do	93.53
30	64	C. Whitman Cross	do	102.58
30	65	C. Willard Hayes	do	159.88
30	66	M. L. Frost	Pasturage, etc	10.80
31	67	C. Whitman Cross	Services, Aug., 1893	168.50
31	68	W. Lindgren	do	151.60
31	69	H. W. Turner	do	151.60
31	70	N. H. Darton	do	134.80
31	71	S. C. Chaney	do	55.00
31	72	W. T. Turner	Services, July, 1893	21.45
31	73	do	Services, Aug. 1893	35.00
31	74	T. Nelson Dale	do	168.50
31	75	L. M. Prindle	do	50.00
31	76	W. H. Weed	do	151.60
31	77	J. Stanley-Brown	do	151.60
31	78	C. R. Van Hise	do	150.00
31	79	Pay roll of employees	do	232.90
31	80	do	do	281.60
31	81	do	do	309.00
31	82	G. K. Gilbert	do	337.00
31	83	Arnold Hague	do	337.00
31	84	George H. Eldridge	do	227.40

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

AUGUST, 1893—Continued.

Date of payment	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug 31	85	Bailey Willis	Services, Aug., 1893	$252.70
31	86	Pay roll of employees	do	955.30
31	87	T. Nelson Dale	Traveling expenses	27.33
31	88	do	Field expenses	1.36
31	89	J. B. Woodworth	Traveling expenses	50.00
31	90	R. E. Dodge	Field expenses	40.00
		Total		8,160.79

SEPTEMBER, 1893.

Sept. 4	1	John A. Udden	Services, Aug., 1893	$130.00
4	2	W. H. Anderson	do	115.00
4	3	J. E. Wolff	do	85.00
4	4	G. K. Gilbert	Field expenses	22.65
4	5	do	Forage	24.24
4	6	Pay roll	Services, Aug., 1893	180.00
4	7	C. K. Leith	Services, July 1-Aug. 31, 1893	8.37
5	8	C. R. Van Hise	Traveling expenses	169.77
5	9	John S. Mendenhall	Supplies	52.67
5	10	G. O. Smith	Services, Aug., 1893	25.00
5	11	Charles Oley	do	75.00
5	12	Arsene Chartrand	do	50.00
5	13	Charles Perry	do	60.00
5	14	W. S. Bayley	do	135.00
5	15	J. Morgan Clements	do	108.00
5	16	T. W. Read & Co	Supplies	38.80
5	17	M. R. Campbell	Field expenses	137.12
6	18	H. W. Turner	do	69.77
7	19	W. H. Utterback	Services, Aug., 1893	50.00
7	20	John Hart	do	70.00
7	21	A. C. Thomas	Subsistence	3.85
7	22	G. K. Gilbert	Field expenses	3.50
7	23	do	do	37.35
9	24	William B. Clark	Services, Aug., 1893	100.00
11	25	Ben. K. Emerson	do	135.00
11	26	R. E. Dodge	Traveling expenses	46.98
12	27	C. Willard Hayes	Field expenses	66.87
13	28	Frank Leverett	Services, July—Aug., 1893	260.00
13	29	E. B. Mathews	Services, Aug., 1893	60.00
15	30	W. L. Wilson	do	60.00
15	31	S. W. Whittaker	do	50.00
15	32	J. S. Diller	do	202.20
15	33	C. Whitman Cross	Field expenses	102.99
19	34	C R. Van Hise	Traveling expenses	105.62
19	35	T. Nelson Dale	do	21.44
20	36	Charles D. Walcott	do	76.01
20	37	John S. Mendenhall	Subsistence	52.37
20	38	do	do	12.50
21	39	George H. Barton	Traveling expenses	75.95
21	40	W. S. Bayley	do	73.37
21	41	A. C. Seass	Boarding	23.00
21	42	A. J. McDonald	Feeding stock	9.00
21	43	Spencer, Mayn & Heitman	Subsistence	79.51
21	44	do	do	16.07
30	45	W. Lindgren	Services, Sept., 1893	146.07
30	46	Pay roll	do	180.00
30	47	L. V. McQuiston	Services, Aug. 1-14, 1893	16.00
30	48	George H. Eldridge	Services, Sept., 1893	220.20
30	49	G. K. Gilbert	do	326.00
30	50	Arnold Hague	do	326.00
30	51	T. Nelson Dale	do	163.00
30	52	W. T. Turner	do	40.00
30	53	H W. Turner	do	146.80
30	54	Walter H Weed	do	146.80
30	55	W. L. Wilson	do	60.00
30	56	S. W. Whitaker	do	50.00
30	57	A. J. Steele	do	60.00
30	58	do	Services, Aug., 1893	60.00
30	59	W. H. Frith	do	60.00
30	60	do	Services, Sept, 1893	60.00
30	61	Louis M. Prindle	do	50.00
30	62	C. Whitman Cross	do	163.00
30	63	Bailey Willis	do	244.60
30	64	Robert T. Hill	Services, Sept. 4-30, 1893	144.00

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

SEPTEMBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 30	65	Pay roll	Services, Sept., 1893	$1,071.20
30	66	C. Whitman Cross	Field expenses	95.17
30	67	Moore & Peak	Pasturage	11.80
30	68	G. K. Gilbert	Field expenses	31.70
30	69	......do	......do	2.90
30	70	P. Warner & Sons	Supplies	34.26
30	71	W. Lindgren	Field expenses	118.40
30	72	Pay roll	Services, Sept., 1893	229.20
30	73	L. H. Davis	......do	30.00
30	74	J. B. Woodworth	......do	50.00
30	75	......do	Traveling expenses	67.91
30	76	H. W. Turner	Field expenses	58.97
30	77	Pay roll	Services, Sept., 1893	257.00
30	78	N. H. Darton	......do	130.40
		Total		8,132.08

OCTOBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 3	1	Andrew C. Lawson	Field expenses	$69.08
3	2	......do	Services, July 1-Aug. 21, 1893	165.00
3	3	Charles Palache	Services, July 1-Aug. 8, 1893	66.00
3	4	T. L. Ransome	Services, Aug., 1893	42.00
4	5	Charles S. Prosser	......do	88.00
4	6	......do	Traveling expenses	11.53
4	7	J. E. Wolff	Services, Sept., 1893	125.00
4	8	R. E. Dodge	Services, Sept. 1-9, 1893	16.00
4	9	C. R. Van Hise	Services, Sept. 1893	200.00
4	10	C. K. Leith	......do	25.62
4	11	Robert T. Hill	Traveling expenses	23.75
5	12	G. K. Gilbert	Field expenses	67.66
5	13	Louis M. Prindle	Traveling expenses	50.05
5	14	J. E. Wolff	......do	73.35
5	15	L. H. Davis	......do	59.77
5	16	Pay roll	Services, Sept., 1893	276.80
7	17	G. K. Gilbert	Field expenses	115.00
7	18	......do	......do	30.00
7	19	......do	......do	13.85
7	20	M. R. Campbell	......do	114.94
7	21	R. E. Dodge	Traveling expenses	27.40
7	22	T. Nelson Dale	......do	49.87
7	23	......do	Field expenses	40
9	24	Legendre & Rochon	Supplies	24.38
9	25	F. H. Kearney & Co	......do	13.25
9	26	John Hart	Services, Sept., 1893	70.00
9	27	W. H. Utterback	......do	50.00
9	28	......do	Services, Oct. 1-3, 1893	4.84
9	29	E. B. Mathews	Services, Sept., 1893	60.00
9	30	Charles Perry	......do	60.00
10	31	H. F. Phillips	......do	60.00
10	32	Charles Oley	......do	75.00
10	33	W. S. Bayley	......do	121.25
10	34	Aleck Longlade	......do	21.00
10	35	Charles Rean	......do	17.50
10	36	Arsene Chartrand	......do	32.50
10	37	W. S. Bayley	Traveling expenses	67.84
12	38	Cyrus C. Babb	......do	24.75
12	39	Ben K. Emerson	Services, Sept., 1893	130.00
12	40	J. E. Wolff	Field expenses	9.54
12	41	Charles S. Prosser	......do	70.50
13	42	C. Whitman Cross	......do	87.88
14	43	Frank Leverett	Services, Sept., 1893	130.00
17	44	Thomas Parry	Traveling expenses	21.00
19	45	W. Lindgren	Field expenses	44.14
19	46	James R. Thompson	Services, Sept., 1893	50.00
24	47	G. K. Gilbert	Field expenses	18.00
24	48	......do	......do	35.75
24	49	......do	......do	.25
24	50	A. C. Peale	Services, Sept., 1893	12.00
24	51	W. & L. E. Gurley	Supplies	3.05
24	52	George H. Eldridge	Traveling expenses	21.50
24	53	......do	Cash paid for expenses	27.90
25	54	Walter H. Weed	Traveling expenses	86.80
25	55	Charles D. Walcott	......do	92.66
25	56	Frank Hollister	......do	21.85
26	57	John Hart	Services, Oct. 1-6, 1893	11 29

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

OCTOBER, 1893—Continued.

Date of payment.	No of voucher.	To whom paid.	For what paid.	Amount.
Oct. 26	58	George H. Eldridge	Field expenses	$120.05
26	59	H. W. Turner	......do	136.71
26	60	Arnold Hague	Traveling expenses	25.95
26	61	W. H. Weed	Cash paid for services	30.96
28	62	W. H. Frith	Services, Oct. 1-15, 1893	29.03
28	63	Arnold Hague	Field expenses	141.32
28	64	......do	Traveling expenses	8.05
28	65	......do	......do	6.00
31	66	Fritz Sohnckind	Services, Sept. 19-Oct. 31, 1893	56 00
31	67	T. Nelson Dale	Services, Oct., 1893	168.50
31	68	W. Lindgren	......do	151.60
31	69	L. H. Davis	......do	30.00
31	70	J. B. Woodworth	......do	50.00
31	71	W. T. Turner	......do	45.00
31	72	H. W. Turner	......do	151.60
31	73	C. Whitman Cross	......do	168.50
31	74	J. S. Diller	......do	202.20
31	75	Walter H. Weed	......do	151.60
31	76	Cyrus C. Babb	......do	84.20
31	77	Pay roll of employees	......do	1,241.70
31	78	Geo. H. Eldridge	......do	227.40
31	79	Bailey Willis	......do	252.70
31	80	Arnold Hague	......do	337.00
31	81	G. K. Gilbert	......do	387.00
31	82	Pay roll of employees	......do	232.90
31	83	T. A. Jaggar, jr	Traveling expenses	27.85
		Total		7,701.31

NOVEMBER, 1893.

Date of payment.	No of voucher.	To whom paid.	For what paid.	Amount.
Nov. 1	1	George H. Eldridge	Field expenses	$5.00
1	2	J. Morgan Clements	Services, Sept., 1893	104.00
1	3	S. W. Whittaker	Services, Oct. 1-27, 1893	43.55
1	4	W. L. Wilson	Services, Oct., 1893	60.00
3	5	C. R. Van Hise	......do	150.00
3	6	C. K. Leith	......do	41.25
3	7	Pay roll of employees	......do	283.86
3	8	John Hart	Traveling expenses	32.90
3	9	Cyrus C. Babb	......do	10.70
6	10	Frank Leverett	Services, Oct., 1893	130.00
6	11	Ben K. Emerson	......do	105.00
6	12	William B. Clark	Services, Sept. 1-Oct. 31, 1893	125.00
6	13	Robert T. Hill	Services, Oct. 1-20, 1893	102.00
8	14	L. H. Davis	Traveling expenses	54.49
8	15	N. H. Darton	Services, Oct., 1893	134.80
8	16	J. S. Diller	Services, Sept., 1893	195.60
8	17	N. S. Shaler	Services, July 1-Nov. 1, 1893	400.00
9	18	W. Lindgren	Field supplies	60.00
11	19	C. Willard Hayes	Field expenses	190.39
11	20	......do	Traveling expenses	39.20
11	21	C. C. Hayes	......do	10.10
11	22	M. R. Campbell	Field expenses	89.47
11	23	G. K. Gilbert	......do	25.55
11	24	......do	......do	33.34
11	25	......do	......do	152.50
11	26	......do	Traveling expenses	49.00
11	27	......do	......do	28.75
11	28	Charles Rean	Services, Oct., 1893	49.19
11	29	H. F. Phillips	......do	57.10
11	30	Aleck Longlade	......do	60.00
11	31	J. Morgan Clements	......do	104 00
11	32	Charles Oley	......do	75.00
11	33	W. S. Bayley	......do	90 00
11	34	Charles Perry	......do	58.06
11	35	John S. Mendenhall	Field expenses	102.19
15	36	G. K. Gilbert	......do	1.25
18	37	Joseph Sellwood & Co	Supplies	10.86
18	38	Joseph Kirkpatrick	......do	12.60
18	39	T. H. Kearney & Co	......do	17.13
18	40	Frank Sharon	Hire of team and hauling	13.50
18	41	C. Whitman Cross	Traveling expenses	63.15
18	42	......do	Field expenses	74.93
22	43	H. W. Turner	......do	114.05
22	44	C. R. Van Hise	......do	38.30

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

NOVEMBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Nov. 23	45	H. W. Turner	Traveling expenses	$38.30
23	46	J. Morgan Clements	......do	92.11
24	47	N. H. Darton	......do	39.86
30	48	H. W. Turner	Services, Nov., 1893	146.80
30	49	W. T. Turner	......do	45.00
30	50	W. Lindgren	......do	146.80
30	51	T. Nelson Dale	......do	163.00
30	52	J. B. Woodworth	......do	50.00
30	53	Pay roll of employees	......do	1,837.40
30	54	......do	......do	1,116.80
30	55	Harry Landes	Traveling expenses	21.60
30	56	Alfred H. Brooks	......do	6.40
30	57	Arthur Keith	Services, Nov., 1893	146.80
		Total		7,448.63

DECEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Dec. 2	1	Pay roll of employees	Services, Nov., 1893	$130.87
2	2	George H. Eldridge	Field expenses	10.00
2	3	E. B. Mathews	Traveling expenses	70.25
5	4	C. K. Leith	Services, Nov , 1893	40.87
5	5	T. E. Morrow	......do	52.05
5	6	H. F. Phillips	......do	57.00
5	7	C. R. Van Hise	......do	150.00
5	8	J. Morgan Clements	......do	76.00
5	9	George H. Williams	Services, Sept. 24–Nov. 30, 1893	165.06
5	10	W. S. Bayley	Services, Nov., 1893	75.00
5	11	Pay roll of employees	......do	96.82
6	12	H. B. Goodrich	Traveling expenses	44.90
6	13	M. R. Campbell	......do	90.95
6	14	R. C. Hamilton	Boarding stock	21.17
7	15	Joseph Douthit	Traveling expenses	4.44
7	16	Arthur Keith	......do	44.05
7	17	......do	Field expenses	142.08
8	18	Frank Leverett	Services, Nov., 1893	130.00
8	19	W. Lindgren	Field expenses	82.90
9	20	C. Whitman Cross	......do	32.45
13	21	Joseph Stanley-Brown	Traveling expenses	125.23
31	22	T. Nelson Dale	Services, Dec., 1893	168.50
31	23	Walter H. Weed	......do	151.60
31	24	Harold B. Goodrich	......do	50.00
31	25	H. W. Turner	......do	151.60
31	26	W. Lindgren	......do	151.60
31	27	W. T. Turner	......do	45.00
31	28	J. B. Woodworth	......do	50.00
31	29	I. M. Buell	Services, July 1–Dec. 9, 1893	80.00
31	30	T. Nelson Dale	Field expenses	1.15
31	31	R. C. Hamilton	Boarding public animals	25.00
31	32	C. K. Leith	Services, Dec., 1893	38.50
31	33	W. S. Bayley	......do	65.00
31	34	C. R. Van Hise	......do	150.00
31	35	James R. Thompson	Services, Oct., 1893	10.00
31	36	J. Morgan Clements	Services, Dec., 1893	100.00
31	37	Pay roll of employees	......do	2,016.70
31	38	......do	......do	1,154.10
31	39	William B. Clark	......do	75.00
		Total		6,125.78

JANUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Jan. 3	1	Isaac Monroe	Traveling expenses	$19.90
6	2	Louis V. Pirsson	......do	55.05
6	3	W. C. Mendenhall	......do	23.15
6	4	H. W. Turner	Field expenses	109.55
9	5	George H. Williams	Services, Dec., 1893	55.00
10	6	F. E. Morrow	......do	63.60
10	7	H. F. Phillips	......do	60.00
10	8	Samuel Storrow	Pasturage, etc	21.50
16	9	Jno. S. Mendenhall	Supplies	4.60
16	10	Steininger & Co	Rent of boats	12.00
19	11	Frank Leverett	Services, Dec., 1893	130.00

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

JANUARY, 1894—Continued

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Jan. 22	12	Andrew C. Lawson	Services, Nov., 11-Dec., 31, 1893	$30.00
22	13	do	Field expenses	25.50
22	14	W. Lindgren	do	63.15
22	15	H. W. Turner	Traveling expenses	116.50
22	16	James McPherson	Pasturage and hay	51.00
23	17	James R. Thompson	Traveling expenses	41.00
30	18	H. W. Turner	Field expenses	20.00
31	19	W. Lindgren	Services, Jan., 1894	155.00
31	20	Walter H. Weed	do	155.00
31	21	H. B. Goodrich	do	50.00
31	22	H. W. Turner	do	155.00
31	23	Pay roll of emyloyees	do	1,179.60
31	24	do	do	2,061.50
31	25	Willard S. Robbins	do	38.71
31	26	J. B. Woodworth	do	50.00
31	27	T. Nelson Dale	do	144.44
31	28	C. M. Harlan	Pasturage	26 00
31	29	Geo. H. Barton	Traveling expenses	30.76
		Total		4,947.51

FEBRUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Feb. 6	1	William B. Clark	Services, Jan., 1894	$50.00
6	2	C. K. Leith	do	37.75
6	3	F. E. Morrow	do	62.40
6	4	W. S. Bayley	do	80.00
6	5	Frank Leverett	do	130.00
6	6	R. C. Hamilton	Boarding stock	25.00
7	7	Bailey Willis	Traveling expenses	9.90
9	8	N. B. Dunn	Pasturage and feeding	69.38
12	9	Walter H. Weed	Field expenses	60.55
12	10	Samuel Storrow	Pasturage and storage	57.50
12	11	do	do	11.50
12	12	do	do	26.50
13	13	W. Lindgren	Field expenses	56.30
23	14	I. M. Buell	Services, Dec. 10, 1893-Jan. 10, 1894	62.50
23	15	L. H. Davis	Services, Feb. 5-7, 1894	5.00
23	16	Warren Upham	Traveling expenses	73.50
23	17	J. S. Diller	do	25.75
28	18	W. Lindgren	Services, Feb, 1894	140.00
28	19	Frederick Koch	Pasturage	117.00
28	20	Spence, Mayn & Heitman	Supplies	28.27
28	21	Benepe, Owenhouse Co	Field material	55.20
28	22	W. B. Benham	Repairs to tents	5.30
28	23	T. Nelson Dale	Services, Feb., 1894	127.78
28	24	R. E. Dodge	Services, Feb. 1-14, 1894	15.00
28	25	J. B. Woodworth	Services, Feb., 1894	50.00
28	26	Harold B. Goodrich	Services, Feb. 1-15, 1894	26.78
28	27	Pay roll of employees	Services, Feb., 1894	2,192.00
28	28	do	do	1,065.80
		Total		4,666.66

MARCH, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Mar. 7	1	Frank Leverett	Services, Feb., 1894	$115.00
7	2	W. S. Bayley	do	75.00
7	3	C. K. Leith	do	36.37
7	4	F. E. Morrow	do	58.20
9	5	R. C. Hamilton	Pasturage	25.00
14	6	C. R. Van Hise	Services, Feb., 1894	230.00
14	7	Samuel Storrow	Foraging, etc	19.00
14	8	N. B. Dunn	do	9.00
14	9	W. Lindgren	Field expenses	67.75
17	10	N. S. Shaler	Services, Nov. 1, 1893-Feb. 28, 1894	400.00
19	11	George H. Barton	Services, July 17-Sept. 23, 1893	52.00
19	12	Max Reimer	Services (job)	4.90
23	13	George H. Eldridge	Traveling expenses	109.93
23	14	do	Field expenses	1.10
24	15	John S. Mendenhall	Field supplies	7.25
30	16	T. Nelson Dale	Services, Mar., 1894	144.44
30	17	J. B. Woodworth	do	50.00
30	18	W. Lindgren	do	155.00

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

MARCH, 1894—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Mar. 30	19	C. R. Van Hise	Services, Mar., 1948	$270.00
30	20	Pay roll of employees	do	1,179.60
30	21	do	do	2,421.50
30	22	I. M. Buell	Services	77.50
30	23	R. C. Hamilton	Boarding stock	25.00
		Total		5,553.54

APRIL, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Apr. 2	1	George H. Eldridge	Traveling expenses	$67.57
5	2	W. Lindgren	Field expenses	103.75
5	3	George H. Williams	Services, Feb. and Mar., 1894	80.00
5	4	Frank Leverett	Services, Mar., 1894	135.00
5	5	Henry Bufford	Services, Mar. 1-14, 1894	24.00
7	6	Max Reimer	Services (job)	41.30
7	7	F. E. Morrow	Services, Mar., 1894	59.40
7	8	C. K. Leith	do	21.50
7	9	W. S. Bayley	do	50.00
7	10	Fred. A. Fielding	Buckboard and harness	75.00
14	11	George H. Eldridge	Field expenses	51.50
14	12	do	do	29.28
14	13	T. Nelson Dale	Traveling expenses	48.76
14	14	A. Bishop	Pasturage, etc	61.00
14	15	Thomas H. Lowe	Pasturage and hay	63.22
14	16	W. H. Weed	Traveling expenses	39.00
16	17	J. F. Barclay	Forage	36.00
16	18	Samuel Storrow	Pasturage, etc	19.00
20	19	Max Reimer	Services	24.50
23	20	C. R. Van Hise	Traveling expenses	83.31
23	21	W. Lindgren	Field expenses	77.30
30	22	C. M. Harlan	Pasturage, etc	74.25
30	23	W. Lindgren	Services, Apr., 1894	148.30
30	24	George H. Williams	do	75.00
30	25	T. Nelson Dale	do	131.87
30	26	J. B. Woodworth	do	50.00
30	27	Pay roll of employees	do	2,319.60
30	28	do	do	1,129.15
		Total		5,118.56

MAY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
May 4	1	F. H. Knowlton	Traveling expenses	$70.19
4	2	R. C. Hamilton	Forage, Apr., 1894	25.00
4	3	C. R. Van Hise	Services, Apr., 1894	180.00
4	4	C. K. Leith	do	47.25
4	5	J. M. Clements	do	96.00
4	6	F. E. Morrow	do	63.30
4	7	Frank Leverett	do	115.00
15	8	W. S. Bayley	Field expenses	11.07
15	9	George H. Eldridge	do	55.96
15	10	T. B. Byrd	do	23.21
15	11	W. Lindgren	do	51.70
15	12	Charles S. Prosser	do	20.45
15	13	do	Traveling expenses	3.31
15	14	A. Bishop, sr	Pasturage	24.00
15	15	A. Buford	Services, Mar. 29-31, 1894	5.81
15	16	do	Services, Apr., 1894	60.00
15	17	W. S. Bayley	do	80.00
16	18	Andrew C. Lawson	do	50.00
21	19	Henry Bufford	do	30 00
23	20	Samuel Storrow	Pasturage	11.50
24	21	H. W. Turner	Traveling expenses	109.00
24	22	J. B. Woodworth	do	21.14
30	23	T. Nelson Dale	Services, May, 1894	131.87
31	24	W. Lindgren	do	153.40
31	25	Pay roll of employees	do	1,166.70
31	26	do	do	2,395.80
31	27	J. B. Woodworth	do	50.00
31	28	Arthur Keith	Traveling expenses	37.80
		Total		5,089 46

Abstract of disbursements made by C. D. Davis, special disbursing agent, U. S. Geological Survey—Continued.

JUNE, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 6	1	A. Buford	Services, May, 1894	$60.00
6	2	C. K. Leith	do	32.00
6	3	J. Morgan Clements	do	94.00
6	4	C. R. Van Hise	do	150.00
6	5	George H. Williams	do	125.00
6	6	F. E. Morrow	do	68.25
6	7	I. M. Buell	do	50.00
6	8	Harold B. Goodrich	Services, Feb. 16–Mar. 15, 1894	47.40
6	9	T. C. Chamberlin	Services, July, 1893–Apr. 1, 1894	270.00
6	10	James McPherson	Pasturage	45.00
6	11	R. C. Hamilton	do	25.00
6	12	Charles S. Prosser	Field expenses	9.70
6	13	do	Traveling expenses	4.65
7	14	W. Lindgren	Field expenses	63.55
18	15	T. C. Chamberlin	Services, Apr. 2–June 16, 1894	110.00
19	16	John A. Udden	Services, June 9–14, 1894	25.00
20	17	N. H. Darton	Traveling expenses	61.96
20	18	George H. Eldridge	Field supplies, etc	66.56
20	19	Frederick Koch	Pasturage, Feb. 12–May 31, 1894	96.42
25	20	A. Buford	Services, June, 1894	28.00
26	21	Samuel Storrow	Pasturage and storage	11.50
27	22	J. S. Diller	Traveling expenses	25.10
29	23	C. Willard Hayes	do	39.05
30	24	J. B. Woodworth	Services, June, 1894	50.00
30	25	R. A. T. Penrose, jr	do	150.00
30	26	Frederick Koch	Pasturage, June, 1894	27.00
30	27	C. Willard Hayes	Services, June, 1894	131.90
30	28	H. W. Turner	do	148.30
30	29	W. Lindgren	do	148.30
30	30	T. Nelson Dale	do	137.36
30	31	Pay roll of employees	do	1,129.15
30	32	do	do	1,368.10
30	33	F. E. Morrow	do	62.40
30	34	J. Morgan Clements	do	104.00
30	35	C. R. Van Hise	do	200.00
30	36	C. S. Prosser	do	72.00
30	37	T. J. Roberts & Son	do	216.35
30	38	T. Nelson Dale	Traveling expenses	9.86
30	39	James Bondurant	Field subsistence	21.16
30	40	C. M. Harlan	2 mules	260.00
30	41	R. C. Hamilton	Board of stock	25.00
30	42	Frank Leverett	Services, May and June, 1894	220.00
30	43	T. Nelson Dale	Field expenses	8.87
		Total		5,997.89

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey, during fiscal year 1893–'94.

JULY, 1893.

Date of payment.	No. of voucher	To whom paid.	For what paid.	Amount.
July 8	1	Theo. H. Lowe	Forage	$55.00
8	2	W. H. Roby & Co	do	16.65
8	3	B. O. Paulsen	Repairs	25.70
8	4	E. D. Sommers & Bro	Subsistence	7.60
8	5	T. M. Bannon	Traveling expenses	20.00
8	6	Robert A. Farmer	do	64.00
8	7	C. C. Bassett	do	28.25
8	8	William H. Herron	do	53.40
8	9	Joseph Macfarland	do	24.25
8	10	James W. Spencer	do	67.95
8	11	Frank Tweedy	do	30.35
8	12	do	Field expenses	36.30
8	13	Overpeck Bros	do	41.50
8	14	Thomas Hughes	Field supplies	43.27
8	15	McFarland & Hillis	Field expenses	15.75
10	16	T. M. Bannon	do	43.92
10	17	do	do	19.70
10	18	Robert A. Farmer	do	117.92
11	19	Frank Tweedy	do	41.96
11	20	H. A. Coffeen & Son	Field supplies	113.76
14	21	E. M. Douglas	Field expenses	75.53

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

JULY, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 14	22	Alex. C. Barclay	Traveling expenses	$38.75
15	23	W. T. Griswold	do	12.25
15	24	W. B. Corse	do	25.75
15	25	R. C. McKinney	do	84.25
15	26	William S. Post	do	107.50
15	27	George O. Glavis, jr	do	84.25
15	28	P. A. Regan & Co	Field supplies	241.38
18	29	Southworth, Grattan & Co	do	22.00
18	30	E. M. Douglas	Field expenses	159.45
18	31	Paul Holman	Traveling expenses	13.50
18	32	R. U. Goode	do	90.00
18	33	Charles B. Green	do	85.25
18	34	W. & L. E. Gurley	Instruments	16.00
20	35	P. Fee	Forage	25.40
20	36	Hahn & Bruch	Subsistence	29.50
20	37	J. C. Mason & Co	do	22.60
20	38	R. D. Cunningham	Field material	245.50
20	39	A. Christensen	do	100.00
20	40	Coffin & Northrup Co	do	150.00
20	41	Southworth, Grattan & Co	Field supplies	110.67
20	42	John T. Oldham & Son	do	60.85
20	43	do	Field expenses	29.47
20	44	R. B. Marshall	do	41.45
20	45	E. T. Perkins, jr	do	123.15
20	46	M. P. Henderson & Son	do	73.77
20	47	do	do	74.80
20	48	do	do	59.40
20	49	Thomas C. Nelson	Traveling expenses	66.90
21	50	F. E. Fellows	do	22.75
21	51	William H. Herron	do	27.25
21	52	Charles F. Urquhart	do	90.00
21	53	Wesley Pratt	do	14.55
21	54	W. T. Griswold	Field expenses	37.85
21	55	H. E. Clermont Feusier	do	17.60
21	56	Mary C. Mahon	Services, July, 1893	33.75
25	57	Ida K. Townsend	Field supplies	76.22
25	58	C. C. Bassett	Field expenses	190.25
25	59	R. B. Marshall	do	44.30
25	60	William H. Herron	do	57.80
25	61	E. M. Douglas	do	109.73
25	62	do	Traveling expenses	60.10
25	63	J. C. Elliott	do	16.55
25	64	W. J. Lloyd	do	78.80
25	65	F. Piper	Forage	8.75
25	66	Robert A. Farmer	Field expenses	63 15
25	67	T. M. Bannon	do	26.97
25	68	do	do	36.79
28	69	H. F. Young & Bro	do	27 00
28	70	M. D. Jordan	do	46 50
28	71	H. G. Pinkston	do	21.57
28	72	F. C. Standish	do	19.00
28	73	R. U. Goode	do	95.20
28	74	Humphries & Co	Field supplies	325.08
28	75	do	Field material	100.00
28	76	J. H Baglor	Transportation	10.00
28	77	R. O. Gordon	Traveling expenses	112.20
28	78	R. Balfour Robertson	do	29.35
28	79	Thomas C. Nelson	do	14.50
29	80	H. R. Crocker	Field supplies	32.06
29	81	Schwartz & Raas	do	128.85
29	82	Thomas J. Keyser	Field expenses	20.35
29	83	W. T. Griswold	do	83.10
29	84	do	do	18.35
29	85	J. L. Carlisle	do	72.20
29	86	William H. Herron	do	75.70
29	87	C. H. Jones	Forage	126.00
31	88	G. W. Hale	do	5.40
31	89	S. Marks & Co	Field supplies	27.10
31	90	R. S. Holland	Subsistence	75.00
31	91	Pay roll	Services, July, 1893	483.48
31	92	do	do	338.17
31	93	do	do	261.24
31	94	do	do	262.89
31	95	do	do	367.37
31	96	do	do	293.82
31	97	do	do	242.68
31	98	do	do	254.20
31	99	do	do	257.90

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

JULY, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 31	100	Pay roll	Services, July, 1893	$255.16
31	101	......do	......do	323.83
31	102	......do	......do	709.12
31	103	......do	......do	284.80
31	104	......do	......do	217.09
31	105	......do	......do	245.00
31	106	......do	......do	404.30
31	107	H. E. Clermont Feusier	......do	48.90
31	108	F. H. Newell	......do	168.50
31	109	C. H. Stone	......do	84.20
31	110	Redick H. McKee	Field expenses	77.54
31	111	Willard D. Johnson	......do	10.50
31	112	J. B. Cannon	Traveling expenses	7.85
31	113	W. L. Reed	Field supplies	19.85
31	114	Vaux & Coe	Field expenses	31.42
		Total		11,265.03

AUGUST, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 4	115	Hahn & Bruch	Subsistence	$34.50
4	116	A. B. Williams	Forage	18.75
4	117	H. R. Crocker	Field supplies	26.19
4	118	Southwick, Grattan & Co	......do	9.99
4	119	A. P. Davis	Field expenses	112.35
4	120	F. H. Newell	......do	253.60
7	121	E. T. Perkins, jr	......do	71.70
7	122	Robert A. Farmer	......do	60.36
7	123	R. C. McKinney	......do	107.88
7	124	W. T. Griswold	......do	43.37
7	125	Milton Marshall	Pasturage	6.45
7	126	Southwick, Grattan & Co	Field supplies	71.44
8	127	A. H. Thompson	Traveling expenses	104.75
18	128	......do	......do	48.10
19	129	E. T. Perkins, jr	......do	22 25
19	130	......do	Field expenses	11.00
19	131	......do	......do	46.30
23	132	E. M. Douglas	......do	118.42
23	133	C. C Bassett	......do	85.73
23	134	Robert A. Farmer	......do	49.95
23	135	T. M. Bannon	......do	107.80
23	136	Frank Tweedy	......do	64.17
23	137	Redick H. McKee	......do	27.95
23	138	J. H. Conrad & Co	Field supplies	77.12
23	139	Churchill & Wooley	......do	28 55
23	140	Humphries & Co	......do	120.60
23	141	......do	......do	103.05
23	142	Seattle Hardware Co	Field material	10.84
23	143	Momsen & Thorne	......do	32.60
23	144	George L. Hutton	Services, July, 1893	26.00
23	145	W. H. Conover	Forage	46.65
23	146	Robert A. Farmer	Field expenses	103.78
23	147	W. B. Corse	......do	44.65
24	148	Redick H. McKee	......do	66.32
25	149	Isaac J. Lewis	Field supplies	67 60
25	150	Redick H. McKee	Field expenses	57 00
25	151	Alex. C. Barclay	......do	40.97
25	152	R O. Gordon	......do	98.70
25	153	William H. Herron	......do	76.95
25	154	R. U. Goode	......do	54.85
25	155	W. McBee	......do	42.72
25	156	John Byron	Field supplies	30.72
25	157	C. W. Marks & Co	......do	18.25
25	158	S. M Froman & Co	......do	19.30
25	159	McDougall Southwick Co	Field material	12.13
25	160	William S. Post	Field expenses	42.60
25	161	Fred Finkbohner	......do	45.00
25	162	R. B. Marshall	......do	79.63
25	163	......do	......do	91.39
25	164	Stuart P. Johnson	......do	57.80
25	165	Thos. G. Gerdine	Traveling expenses	95.99
25	166	Irwin & Co	Storage	20.00
25	167	M. P. Henderson & Son	......do	12.00
25	168	P. Fee	Forage	86.80
25	169	The A. Lietz Co	Repairs	20.40

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

AUGUST, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 25	170	Ad. Frese & Co	Instruments	$9.00
26	171	E. M. Douglas	Field expenses	105.38
26	172	Southwick, Grattan & Co	Field supplies	130.80
26	173	......do	......do	29.29
26	174	T. M. Bannon	Field expenses	67.79
29	175	F. H. Newell	......do	52.70
29	176	......do	Traveling expenses	151.00
29	177	J. C. Johnson & Co	Field material	16.25
31	178	Vaux & Coe	Forage	19.90
31	179	E. T. Perkins, jr	Field expenses	155.85
31	180	A. P. Davis	......do	174.53
31	181	Pay roll	Services, Aug., 1893	208.82
31	182	......do	......do	244.80
31	183	......do	......do	257.90
31	184	......do	......do	234.20
31	185	......do	......do	480.89
31	186	......do	......do	344.80
31	187	......do	......do	261.60
31	188	......do	Services, July, 1893	261.60
31	189	......do	Services, Aug., 1893	284.80
31	190	......do	......do	284.20
31	191	......do	......do	340.60
31	192	......do	......do	219.90
31	193	......do	......do	243.19
31	194	A. H. Thompson	......do	252.79
31	195	F. H. Newell	......do	168.50
31	196	E. M. Douglas	......do	168.50
31	197	James W. Spencer	......do	151.60
31	198	C. H. Stone	......do	84.20
31	199	Pay roll	......do	302.90
31	200	Edward Kübel	Repairs	79.00
31	201	Pay roll	Services, Aug., 1893	268.50
		Total		9,289.74

SEPTEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 1	202	H. M. Waterbury	Transportation	$10.50
1	203	......do	Forage	57.00
1	204	......do	Storage	8.00
1	205	James W. Spencer	Field expenses	12.35
1	206	......do	Traveling expenses	8.65
1	207	Pay roll	Services, Aug., 1893	282.10
1	208	......do	......do	314.80
1	209	......do	......do	254.20
2	210	......do	......do	324.80
5	211	E. M. Douglas	Traveling expenses	61.85
5	212	W. T. Griswold	......do	8.00
5	213	......do	Field expenses	82.92
5	214	T. M. Bannon	......do	32.35
5	215	Alex. C. Barclay	......do	18.00
5	216	Studebaker Bros. Manufacturing Co.	Field material	125.00
5	217	H. R. Crocker	Field supplies	72.19
5	218	Humphris & Co	......do	85.92
5	219	Schwartz & Raas	......do	59.75
5	220	J. Jepson & Son	......do	29.75
5	221	M. P. Reynolds	Repairs	44.30
5	222	M. P. Henderson & Son	Storage	12.00
5	223	Jackson D. McCarty	Forage	3.50
6	224	W. B. Corse	Field expenses	196.04
6	225	T. M. Bannon	......do	74.96
8	226	E. C. Hammond	......do	12.50
11	227	Redick H. McKee	......do	24.15
11	228	......do	......do	58.70
11	229	R. C. McKinney	......do	255.66
11	230	Alex. C. Barclay	......do	21.40
11	231	R. B. Marshall	......do	65.79
11	232	William S. Post	......do	100.35
11	233	S. M. Froman & Co	Field supplies	19.55
11	234	Southworth, Grattan & Co	......do	24.35
11	235	H. C. Bryant	......do	29.87
11	236	P. J. Cronin	Field material	38.25
11	237	W. H. Conover	......do	15.00

Abstract of disbursements made by James W. Spencer, special disbursing agent U. S. Geological Survey—Continued.

SEPTEMBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 11	238	W. H. Conover	Forage	$68.10
12	239	A. H. Thompson	Traveling expenses	76.75
15	240	Richard Ewart	Services, July, 1893	14.94
15	241	E. M. Douglas	Field expenses	143.39
15	242	T. M. Bannon	do	47.22
18	243	Robert A. Farmer	do	109.35
18	244	do	do	15.15
18	245	do	Traveling expenses	18.70
18	246	C. L. Stevens	Services, Sept., 1893	25.00
18	247	W. B. Corse	Field expenses	77.55
19	248	William H. Herron	do	77.20
18	249	Alex. C. Barclay	do	62.49
19	250	Schwartz & Raas	Field supplies	89.25
20	251	C. C. Bassett	Field expenses	225.73
20	252	A. H Thompson	Traveling expenses	68.90
22	253	Mary C. Mahon	Services, July-Aug., 1893	13.50
22	254	Owen Jones	Services, Aug., 1893	4.83
25	255	E. T. Perkins, jr	Field expenses	55.20
25	256	Charles F. Urquhart	do	148.55
25	257	C. R. Hough	Traveling expenses	27.40
26	258	R. U. Marshall	Field expenses	70.28
26	259	W. T. Griswold	do	29.58
27	260	E. M. Douglas	do	55.45
28	261	E. P. Washburn	do	17.25
28	262	Henry W. Brooke	Repairs	37.00
28	263	Thomas H. Clark	Services, Aug.-Sept., 1893	57.00
28	264	R. U. Goode	Field expenses	48.10
29	265	Robert A. Farmer	do	42.50
29	266	Frank Tweedy	do	26.35
29	267	Redick H. McKee	do	96.70
29	268	J. M. Frost	Field supplies	42.40
30	269	Pay roll	Services, Sept., 1893	287.75
30	270	do	do	241.60
30	271	do	do	280.40
30	272	do	do	213.00
30	273	do	do	668.20
30	274	do	do	320.40
30	275	C. H. Stone	do	81.60
30	276	Pay roll	do	81.60
30	277	do	do	340.40
30	278	do	do	240.40
30	279	do	do	256.80
30	280	do	do	333.80
30	281	do	do	270.00
30	282	do	do	299.20
30	283	Rush & Evvers	Field expenses	18.00
30	284	H. R. Crocker	Forage	130.00
30	285	Vaux & Coe	do	43.58
30	286	The Denver Transit and Warehouse Co.	Storage	30.00
30	287	Schwartz & Raas	Field supplies	87.80
30	288	F. H. Newell	Field expenses	179.65
30	289	C. C. Bassett	do	170.02
30	290	W. B. Corse	do	122.92
30	291	Pay roll	Services, Sept., 1893	275.80
30	292	do	do	181.60
30	293	H. C. Bryant	Field expenses	18.99
30	294	R. C. McKinney	do	123.39
30	295	Humphries & Co	Field supplies	178.90
30	296	Pay roll	Services, Sept., 1893	310.40
30	297	J. W. Brewster	Storage	45.00
		Total		10,567.41

OCTOBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 6	1	A. G. Davis	Field expenses	$223.50
6	2	R. A. At Lee	Services, Sept., 1893	6.66
6	3	Pay roll	do	254.20
6	4	do	do	264.10
6	5	do	do	249.00
6	6	do	do	435.79
9	7	R. C. McKinney	Field expenses	49.30
9	8	A. H. Thompson	Traveling expenses	48.00
10	9	R. S. Donaldson	Services, Oct., 1893	17 50

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

OCTOBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 10	10	Paul Holman	Field expenses	$103.50
10	11	E. T. Perkins, jr	......do	156.40
10	12	Willard D. Johnson	......do	63.40
11	13	E. M. Douglas	......do	74.01
11	14	W. T. Griswold	......do	56.00
11	15	T. M. Bannon	......do	91.97
13	16	Denver and Rio Grande Express Co.	......do	7.65
14	17	Frank P. Morgan	Traveling expenses	31.15
14	18	John Finch	Repairs	8.00
14	19	J. B. Cook	Subsistence	11.75
20	20	W. B. Corse	Traveling expenses	24.00
21	21	Robert A. Farmer	......do	10.50
21	22	......do	Field expenses	58.95
21	23	......do	......do	42.75
23	24	William H. Herron	......do	61.50
23	25	E. M. Douglas	......do	78.37
23	26	T. M. Bannon	......do	98.47
23	27	E. T. Perkins, jr	......do	145.15
23	28	Redick H. McKee	......do	49.30
23	29	Alex. C. Barclay	......do	81.16
23	30	......do	......do	50.67
23	31	W. B. Corse	......do	65.14
23	32	......do	......do	36.74
23	33	F. H. Newell	Traveling expenses	64.15
23	34	George O. Glavis, jr	......do	76.25
23	35	Joseph Macfarland	......do	24.00
23	36	R. C. McKinney	......do	76.00
23	37	W. H. Conover	Forage expenses	55.60
23	38	Studebaker Bros. Manufacturing Co.	Field material	50.00
23	39	The Lewis and Dryden Co	Maps	86.00
23	40	Frank P. Morgan	Services, Aug., 1893	9.67
23	41	......do	Services, Sept., 1893	50.00
23	42	George W. Walker	......do	50.00
24	43	Foster Longhead	Services, July, 1893	14.00
24	44	A. W. Longhead	...... do	14.00
24	45	P. Fee	Forage	56.60
24	46	......do	......do	27.70
24	47	Coffman & Kenney	......do	10.70
24	48	J. B. Cook	Subsistence	12.00
24	49	Hahn & Bruch	......do	25.50
24	50	H. R. Crocker	......do	34.06
24	51	......do	Forage	54.00
24	52	......do	Field supples	98.84
24	53	......do	Field expenses	14.00
24	54	M. P. Henderson & Son	......do	36.25
24	55	John Finch	......do	12.50
24	56	Willard D. Johnson	......do	36.45
24	57	......do	......do	30.02
24	58	R. B. Marshall	......do	70.75
24	59	Paul Holman	......do	134.58
24	60	......do	......do	45.60
24	61	William S. Post	......do	250.97
24	62	A. H. Thompson	Traveling expenses	130.90
24	63	Alamo Hotel	Subsistence	46.50
26	64	R. B. Marshall	Field expenses	133.58
26	65	W. B. Corse	......do	77.09
26	66	H. E. C. Feusier	Services, July, 1893	30.97
26	67	......do	Services, Aug., 1893	60.00
27	68	Western Union Telegraph Co	Field expenses	12.38
27	69	Frank P. Morgan	Traveling expenses	32.65
31	70	Pay roll	Services, Oct, 1893	588.80
31	71	......do	......do	257.90
31	72	......do	......do	293.50
31	73	......do	......do	333.67
31	74	......do	......do	254.47
31	75	......do	......do	271.89
31	76	......do	......do	317.90
31	77	......do	......do	282.10
31	78	......do	......do	958.58
31	79	C. H. Stone	......do	84.20
31	80	W. J. Lloyd	Services, Sept., 1893	15.00
31	81	T. M. Bannon	Field expenses	46.90
31	82	Humphries & Co	Field supplies	59.77
31	83	Vaux & Coe	Forage	52.03
31	84	Pay roll	Services, Oct., 1893	393.34
31	85	......do	......do	233.33

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

OCTOBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 31	86	Pay roll	Services, Oct, 1893	$218.50
31	87	......do	......do	212.21
31	88	Redick H. McKee	Field expenses	69.05
31	89	Pay roll	Services, Oct., 1893	234.20
		Total		10,176.18

NOVEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Nov. 3	90	C. C. Bassett	Traveling expenses	$61.75
3	91	Robert A. Farmer	......do	45.75
3	92	Thomas C. Nelson	......do	28.45
3	93	F. H. Newell	......do	49.70
3	94	R. B. Marshall	Field expenses	102.54
3	95	Thomas C. Nelson	Services, Oct., 1893	50.00
3	96	Pay roll	......do	261.60
4	97	W. T. Griswold	Field expenses	88.53
6	98	Paul Holman	......do	89.95
6	99	William S. Post	......do	138.15
6	100	C. C. Bassett	......do	212.20
6	101	Frank Tweedy	......do	41.05
6	102	......do	Traveling expenses	31.10
6	103	W. B. Corse	......do	51.75
6	104	Schwartz & Raas	Field supplies	35.35
6	105	James King	Forage	105.00
6	106	R. S. Holland	Subsistence	14.00
6	107	R. O. Gordon	Services, Oct., 1893	134.80
6	108	C. R. Hough	......do	50.00
7	109	W. H. Conover	Forage	28.75
7	110	W. B. Corse	Field expenses	17.92
7	111	William H Herron	......do	26.80
7	112	E. M. Douglas	......do	85.34
8	113	Patterson & Co	......do	18.00
8	114	M. P. Henderson & Son	Storage	16.00
8	115	L. A. Ritchard	Pasturage	14.00
8	116	Robert Ritschard	Services, Oct., 1893	40.00
15	117	D. C. Bacon	Pasturage	11.00
15	118	R. O. Gordon	Traveling expenses	78.25
15	119	......do	Field expenses	132.74
15	120	Robert A. Farmer	......do	62.95
15	121	Matt. G. Wilkins	Subsistence	24.00
15	122	Charles G. Belknap	Services, Oct., 1893	9.03
16	123	F. H. Newell	......do	168.50
16	124	Charles B. Green	Traveling expenses	45.20
16	125	......do	Field expenses	10.05
16	126	A. P. Davis	......do	58.65
17	127	Joseph Macfarland	Traveling expenses	22.25
25	128	C. R. Hough	......do	81.75
27	129	Robert A. Farmer	Field expenses	60.75
27	130	W. T. Griswold	......do	15.70
27	131	Alex. C. Barclay	......do	99.69
28	132	E. T. Perkins, jr	......do	12.00
29	133	A. H. Thompson	Traveling expenses	114.49
29	134	William H. Herron	......do	69.70
29	135	R. U. Goode	......do	114.40
29	136	......do	Field expenses	49.31
29	137	James W. Spencer	Traveling expenses	61.40
30	138	Charles B. Green	Services, Nov., 1893	81.60
30	139	R. O. Gordon	......do	130.40
30	140	Frank P. Morgan	Services, Oct., 1893	38.71
30	141	Charles H. Strover	Services, Nov., 1893	30.00
30	142	Charles W. Howell	......do	60.00
30	143	Pay roll	......do	202.80
30	144	......do	......do	153.26
30	145	......do	......do	294.60
30	146	......do	......do	304.60
30	147	......do	......do	391.46
30	148	......do	......do	2,208.80
30	149	Redick H. McKee	Field expenses	62.27
30	150	Paul Holman	......do	187.35
30	151	Charles F. Urquhart	......do	228.88
30	152	Frank Tweedy	......do	87.52
30	153	Charles F. Urquhart	Traveling expenses	80.00
30	154	F. H. Newell	......do	117.90
		Total		7,830.44

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

DECEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Dec. 4	155	W. J. Lloyd	Traveling expenses	$69.70
6	156	E. T. Perkins, jr	Field expenses	12.00
6	157	Jas. W. Spencer	......do	10.89
6	158	F. O. Perry	Pasturage	21.23
6	159	Redick H. McKee	Services, Nov., 1893	130.40
7	160	Pay roll	......do	254.20
9	161	Humphries & Co	Pasturage	15.43
11	162	E. M. Douglas	Field expenses	136.23
11	163	T. M. Bannon	Traveling expenses	67.25
11	164	R. A. At Lee	Services, Dec., 1893	6.45
13	165	C. C. Bassett	Field expenses	15.00
15	166	A. P. Davis	......do	21.00
15	167	T. M. Bannon	......do	82.76
16	168	Howard G. Heisler	Services, Nov., 1893	40.00
16	169	E. M. Douglas	Field expenses	45.49
18	170	T. M. Bannon	......do	58.72
19	171	Stuart P. Johnson	......do	42.26
19	172	Wells, Fargo & Co.'s Express	Transportation	11.85
21	173	E. M. Douglas	Traveling expenses	88.75
21	174	Robert A. Farmer	......do	69.75
21	175	Willard D. Johnson	......do	57.00
22	176	Samuel McDowell	Forage	171.60
26	177	W. T. Griswold	Field expenses	57.41
22	178	R. B. Marshall	......do	131.97
26	179	William S. Post	......do	159.02
26	180	Paul Holman	......do	203.75
26	181	Chas. B. Green	Traveling expenses	59.75
26	182	Patterson & Co	Transportation	9.00
30	183	Theodore H. Lowe	Pasturage	55.93
30	184	James King	......do	25.90
30	185	William D. Thomas	Storage	15.00
30	186	Redick H. McKee	Field expenses	23.25
31	187	Chas. W. Howell	Services, Dec., 1893	60.00
31	188	Pay roll	......do	358.54
31	189	......do	......do	361.10
31	190	......do	......do	302.70
31	191	......do	......do	2,763.33
31	192	Redick H. McKee	......do	134.80
31	193	E. T. Perkins, jr	Field expenses	24.37
31	194	The Denver Transit and Warehouse Co.	Storage	30.00
31	195	Robert Flormann	......do	15.00
31	196	John W. Parker	Pasturage	88.01
31	197	E. T. Perkins, jr	Field expenses	12.00
		Total		6,318.70

JANUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Jan 5	1	R. O. Gordon	Traveling expenses	$59.75
13	2	A. H. Thompson	......do	161.18
20	3	R. O. Gordon	Field expenses	347.95
20	4	F. H. Newell	......do	265.68
20	5	W. T. Griswold	......do	36.38
20	6	Redick H. McKee	......do	17.50
20	7	Don Hardy	Services, Nov.-Dec., 1893	36.00
20	8	F. O. Perry	Pasturage	16.00
20	9	Humphries & Co	......do	13.00
22	10	T. M. Alvord	......do	20.00
26	11	M. P. Henderson & Son	Storage	32.00
26	12	R. B. Marshall	Field expenses	24.52
26	13	......do	......do	176.83
26	14	W. S. Post	......do	107.85
26	15	Stuart P. Johnson	Traveling expenses	106.00
29	16	Charles B. Green	Field expenses	8.40
31	17	A. P. Davis	......do	61.00
31	18	Redick H. Mckee	Services, Jan., 1894	137.80
31	19	Charles W. Howell	......do	60.00
31	20	Pay roll	......do	335.50
31	21	......do	......do	316.70
31	22	......do	......do	2,818.63
31	23	......do	......do	308.30
31	24	E. T. Perkins, jr	Field expenses	12.00
		Total		5,478.77

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

FEBRUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Feb. 5	25	Frank E. Gove	Instruments	$16.36
5	26	F. O. Perry	Pasturage	16.00
16	27	Humphries & Co	do	13.00
16	28	W. S. Post	Field expenses	81.35
16	29	Redick H. McKee	do	17.05
16	30	W. T. Griswold	do	30.00
18	31	M. C. Mahon	Services, Jan., 1894	28.00
23	32	L. O. Simmons	Services, Oct., 1893	6.45
24	33	Frank Tweedy	Field expenses	19.33
27	34	Thomas G. Gerdine	Traveling expenses	10.00
28	35	A. P. Davis	Field expenses	13.86
28	36	Pay roll	Services, Feb., 1894	1,572.73
28	37	do	do	283.40
28	38	Redick H. McKee	do	124.40
28	39	Charles W. Howell	do	60.00
28	40	M. C. Mahon	do	21.00
28	41	Pay roll	do	218.80
28	42	do	do	309.00
		Total		3,840.73

MARCH, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Mar. 7	43	Theo. H. Lowe	Pasturage	$66.78
8	44	F. O. Perry	do	16.00
8	45	Humphries & Co	do	13.00
8	46	W. S. Post	Field expenses	78.45
8	47	E. T. Perkins, jr	do	12.00
10	48	A. C. Harvey	Pasturage	55.00
13	49	M. P. Henderson & Son	Storage	32.00
19	50	T. M. Alvord	Pasturage	25.00
19	51	Redick H. McKee	Field expenses	14.00
26	52	F. H. Newell	do	82.00
31	53	A. P. Davis	do	32.50
31	54	E. T. Perkins, jr	do	43.50
31	55	R. B. Marshall	do	53.00
31	56	W. S. Post	do	57.90
31	57	William D. Thomas	Storage	15.00
31	58	The Denver Transit and Warehouse Co.	do	30.00
31	59	Robert Florman	do	15.00
31	60	John W. Parker	Pasturage	168.00
31	61	Humphries & Co	do	13.00
31	62	A. H. Washburn	do	260.97
31	63	Theo. H. Lowe	do	33.60
31	64	Don Hardy	Services, Jan.-Feb.-Mar., 1894	72.00
31	65	Redick H. McKee	Services, Mar., 1894	137.80
31	66	Charles W. Howell	do	60.00
31	67	Pay roll	do	308.30
31	68	do	do	230.60
31	69	do	do	2,818.63
		Total		4,743.53

APRIL, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Apr. 5	1	F. O. Perry	Pasturage	$16.00
5	2	T. M. Alvord	do	10.00
5	3	R. B. Marshall	Field expenses	15.55
5	4	William H. Otis	do	27.85
5	5	Redick H. McKee	do	18.00
7	6	M. C. Mahon	Services, Mar.-Apr., 1894	24.00
9	7	W. S. Rockwell	Forage	12.75
10	8	Pay roll	Services, Mar., 1894	335.50
11	9	W. T. Griswold	Field expenses	23.00
12	10	do	Traveling expenses	6.15
12	11	do	Field expenses	30.90
30	12	Pay roll	Services, Apr., 1894	297.20
30	13	Redick H. McKee	do	131.90
30	14	Pay roll	do	323.70
30	15	do	do	2,709.48
30	16	R. B. Marshall	do	115.40
30	17	Pay roll	do	110.00
		Total		4,207.38

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

MAY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
May 3	18	F. H. Newell	Field expenses	$75.00
8	19	Brewen Bros	do	9.50
8	20	A. P. Davis	do	10.50
8	21	E. T. Perkins, jr	do	12.00
8	22	The A. Lietz Co	Repairs	11.40
8	23	Tie Sing	Services, Apr., 1894	16.50
8	24	F. O. Perry	Services, Mar., 1894	16.00
8	25	do	Pasturage	16.00
8	26	Humphries & Co	do	13.00
8	27	James King	do	33.00
8	28	A. C. Harvey	do	16.50
8	29	Lake Farm Club	Forage	52.50
8	30	W. E. Rockwell	do	10.50
8	31	do	do	11.25
8	32	William E. Nason	do	10.50
8	33	do	do	10.50
8	34	R. B. Marshall	Traveling expenses	39.00
9	35	Charles W. Howell	Services, Apr., 1894	60.00
10	36	Redick H. McKee	Field expenses	21.85
15	37	Perry Fuller	Services	84.00
16	38	W. S. Post	Field expenses	80.95
19	39	L. M. Lassell Co	Forage	22.99
21	40	W. B. Corse	Traveling expenses	26.00
22	41	William E. Nason	Forage	22.50
24	42	W. T. Griswold	Field expenses	26.25
31	43	F. O. Perry	Forage	16.00
31	44	Humphries & Co	do	13.00
31	45	Redick H. McKee	Services, May, 1894	136.20
31	46	Pay roll	do	305.60
31	47	do	do	146.60
31	48	do	do	349.20
31	49	do	do	121.60
31	50	do	do	2,817.70
31	51	Charles W. Howell	do	60.00
31	52	W. B. Corse	Field expenses	51.45
31	53	R. B. Marshall	do	32.70
31	54	George O. Glavis, jr	Traveling expenses	19.00
		Total		4,777.24

JUNE, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 4	55	M. P. Henderson & Son	Storage	$48.00
8	56	Spratlen & Anderson	Field supplies	47.24
8	57	R. O. Gordon	Traveling expenses	20.50
9	58	Charles B. Green	do	60.50
11	59	E. T. Perkins, jr	do	50.10
11	60	do	Field expenses	12.00
11	61	W. B. Corse	do	94.26
11	62	W. S. Post	do	57.60
11	63	T. M. Alvord	Pasturage	20.00
12	64	Redick H. McKee	Field expenses	21.75
12	65	W. T. Griswold	do	65.58
12	66	Alex. C. Barclay	do	15.50
13	67	A. P. Davis	Traveling expenses	87.75
13	68	Anderson & Chanslor	Field supplies	23.59
14	69	A. H. Washburn	Pasturage	182.50
19	70	Lee & Glass	Field expenses	20.00
19	71	Alex. C. Barclay	do	12.50
19	72	P. M. Mathews	do	16.00
19	73	C. W. Parks & Co	Storage	15.00
19	74	Jos. Du Bois	Subsistence	32.25
19	75	Shields & Humphrey	Field supplies	28.35
20	76	S. S. Gannett	Traveling expenses	38.50
22	77	R. O. Gordon	Field expenses	133.64
22	78	A. C. Marks	Pasturage	245.58
23	79	Owen Jones	Services, June, 1894	6.65
23	80	William H. Otis	Field expenses	1.00
25	81	Alex. C. Barclay	do	13.50
25	82	Ely Bangs	Forage	12.00
25	83	Gray & Sons	Subsistence	34.13
25	84	F. L. Chambers	Field supplies	25.95
26	85	P. A. Regan & Co	do	110.00
26	86	E. T. Perkins, jr	Field expenses	98.95
26	87	W. T. Griswold	do	54.01
28	88	R. O. Gordon	do	19.65

Abstract of disbursements made by James W. Spencer, special disbursing agent, U. S. Geological Survey—Continued.

JUNE, 1894—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 28	89	Spratlen & Anderson	Field supplies	$36.13
28	90	T. M. Bannon	Traveling expenses	23.75
30	91	Theo. H. Lowe	Pasturage	79.60
30	92	F. O. Perry	......do	16.00
30	93	Humphries & Co	......do	13.00
30	94	James King	......do	70.00
30	95	John W. Parker	......do	117.97
30	96	E. W. Peck	Storage	48.00
30	97	The Denver Transit and Warehouse Co.	......do	30.00
30	98	Don Hardy	Services, Apr.-May-June, 1894	72.00
30	99	Mary C. Mahon	Services, June, 1894	67.50
30	100	Pay roll	......do	347.20
30	101	......do	......do	294.30
30	102	......do	......do	231.60
30	103	......do	......do	1,981.15
30	104	......do	......do	169.20
30	105	......do	......do	215.40
30	106	F. H. Newell	......do	164.80
30	107	B. Mahony	Forage	24.78
30	108	A. H. Washburn	Pasturage	60.00
30	109	M. P. Henderson & Son	Storage	16.00
30	110	T. M. Alvord	Pasturage	12.50
30	111	E. M. Douglas	Traveling expenses	73.35
30	112	Redick H. McKee	Field expenses	17.35
30	113	R. B. Marshall	......do	103.72
30	114	W. B Corse	......do	65.45
30	115	William D. Thomas	Storage	15.00
30	116	Pay roll	Services, June, 1894	160.40
30	117	F. H. Newell	Field expenses	105.57
30	118	......do	Traveling expenses	218.85
30	119	Pay roll	Services, June, 1894	290.40
30	120	R. O. Gordon	Field expenses	17.50
		Total		6,883.00

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey, during fiscal year 1893–'94.

JULY, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 17	1	Hersey Munroe	Traveling expenses	$23.80
17	2	A. E. Murlin	......do	23.50
17	3	Charles E. Cooke	......do	35.86
17	4	F. P. Metzger	......do	6.75
17	5	W. L. Miller	......do	9.00
17	6	John Mason Brown	......do	7.50
17	7	James C. Cook	......do	8.00
17	8	Hersey Munroe	Field expenses	82.65
17	9	Charles E. Cooke	......do	112.60
17	10	William J. Peters	......do	35.65
17	11	Bayless & Moody	Field material	190.05
17	12	John Wehrle	Field expenses	9.00
17	13	H. S. Wallace	Traveling expenses	27.50
18	14	J. M. Woodward	......do	17.50
18	15	W. and L. E. Gurley	Instruments	19.50
18	16	A. E. Murlin	Field expenses	104.71
18	17	......do	......do	29.30
20	18	R. M. Towson	......do	71.13
22	19	F. H. Seely	......do	53.00
22	20	H. B. Blair	......do	75.25
22	21	M. Hackett	......do	100.71
22	22	......do	Traveling expenses	20.45
22	23	J. C. Williams	......do	5.25
24	24	W. and L. E. Gurley	Instruments	13.00
24	25	M. Heldmann	Field supplies	30.35
24	26	Hersey Munroe	Field expenses	7.50
25	27	Van H. Manning	......do	105.38
25	28	Hersey Munroe	......do	39.52

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

JULY, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
July 25	29	George T. Hawkins	Traveling expenses	$114.00
25	30	J. R. Ellis	do	30.80
25	31	H. L. Baldwin, jr	do	40.05
25	32	Fowler & Robison	Repairs to field material	16.75
31	33	Pay roll	Services, July, 1893	1,177.70
31	34	do	do	382.53
31	35	do	do	400.60
31	36	do	do	352.90
31	37	do	do	328.70
31	38	John H. Renshawe	do	185.30
31	39	H. M. Wilson	do	210.60
31	40	H. S. Wallace	do	134.80
31	41	P. H. Christie	do	151.60
31	42	F. H. Seely	do	75.80
31	43	John Wilson	do	14.67
31	44	Pay roll	do	77.41
31	45	do	do	263.77
31	46	do	do	193.70
31	47	do	do	197.90
31	48	do	do	456.40
31	49	do	do	219.34
31	50	do	do	170.78
31	51	do	do	255.60
31	52	do	do	160.00
31	53	do	do	234.80
31	54	do	do	211.60
31	55	do	do	211.10
31	56	A. F. Dudley	do	70.80
31	57	B. C. Washington, jr	do	101.10
31	58	S. S. Gannett	do	168.50
31	59	H. S. Wallace	Field expenses	39.00
31	60	Frank Sutton	Services, July, 1893	134.80
31	61	J. H. Wheat	do	75.80
31	62	H. Ralston Connell	do	60.00
31	63	Pay roll	do	335.60
31	64	do	do	217.90
31	65	William J. Peters	Field expenses	116.60
31	66	Ralph Kitchen	Subsistence	126.00
31	67	C. G. Van Hook	Traveling expenses	51.25
31	68	J. L. Johnson	do	12.30
31	69	Pay roll	Services, July, 1893	244.80
31	70	A. E. Murlin	Field expenses	92.77
		Total		9,380.83

AUGUST, 1893.

Aug. 4	1	Van H. Manning	Field expenses	$301.94
4	2	F. H. Seely	do	60.00
4	3	E. C. Barnard	do	37.00
5	4	Haislett, Nicholson & Co	Field material	5.00
7	5	A. F. Dudley	Services, Aug. 1–6, 1893	13.70
7	6	do	Traveling expenses	23.75
7	7	John H. Renshawe	do	93.58
8	8	William J. Peters	Field expenses	133.75
8	9	R. M. Towson	do	84.27
8	10	George T. Hawkins	do	130.98
8	11	D. C. Harrison	do	202.00
8	12	Charles E. Cook	do	77.19
8	13	Hersey Munroe	do	28.43
15	14	M. Hackett	do	78.16
15	15	Van H. Manning	do	35.16
16	16	H. B. Blair	do	165.40
16	17	George T. Hawkins	do	90.90
16	18	H. L. Baldwin, jr	do	81.22
16	19	do	do	105.15
18	20	Sam Feland	Traveling expenses	13.75
18	21	George T. Hawkins	do	48.20
18	22	Hersey Munroe	Field expenses	17.36
18	23	A. E. Murlin	do	67.78
21	24	H. S. Wallace	do	57.00
22	25	B. G. Benson	Traveling expenses	12.00
25	26	Van H. Manning	Field expenses	105.15
25	27	F. H. Seely	do	59.25

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

AUGUST, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Aug. 26	28	H. L. Baldwin, jr	Field expenses	$87.00
26	29	......do	......do	101.20
31	30	Pay roll	Services, Aug., 1893	1,101.90
31	31	......do	......do	400.60
31	32	......do	......do	312.70
31	33	......do	......do	287.40
31	34	John H. Renshawe	......do	185.30
31	35	H. M. Wilson	......do	210.60
31	36	H. S. Wallace	......do	134.80
31	37	Gilbert Thompson	......do	227.40
31	38	J. H. Wheat	......do	75.80
31	39	F. H. Seely	......do	75.80
31	40	Pay roll	......do	328.70
31	41	......do	......do	400.60
31	42	......do	......do	150.00
31	43	......do	......do	211.10
31	44	......do	......do	210.00
31	45	......do	......do	260.76
31	46	......do	......do	244.80
31	47	H. Ralston Connell	......do	60.00
31	48	Frank Sutton	......do	134.80
31	49	S. S. Gannett	......do	168.50
31	50	B. C. Washington, jr	......do	101.10
31	51	Pay roll	......do	193.70
31	52	J. T. Withrow & Co	Hire of transportation	30.00
31	53	E. E. Dodge	Subsistence	28.10
31	54	Pay roll	Services, Aug., 1893	219.98
31	55	......do	......do	158.52
31	56	......do	......do	167.90
31	57	......do	......do	352.90
31	58	......do	......do	456.40
31	59	......do	......do	321.09
31	60	E. C. Barnard	Field expenses	9.25
31	61	......do	Traveling expenses	21.17
31	62	John H. Renshawe	......do	69.45
31	63	John D. McRae	......do	22.45
31	64	Berry Thompson	......do	10.90
31	65	Walter N. Beecher	Field material	74.25
31	66	H. L. Baldwin, jr	Field expenses	48.95
31	67	R. M. Towson	......do	170.35
31	68	H. B. Blair	......do	85.70
31	69	Van H. Manning	......do	86.63
31	70	Pay roll	Services, Aug., 1893	196.10
31	71	......do	......do	244.80
31	72	H. L. Baldwin, jr	Field expenses	78.25
31	73	Pay roll	Services, Aug., 1893	197.90
31	74	D. C. Harrison	Field expenses	165.75
31	75	Hersey Munroe	......do	27.16
		Total		11,036.58

SEPTEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 6	1	Henry Gannett	Traveling expenses	$135.63
6	2	H. M. Wilson	......do	155.73
8	3	John R. Warner	Field material and supplies	463.40
9	4	A. E. Murlin	Field expenses	68.27
9	5	......do	......do	59.93
9	6	Charles E. Cooke	......do	88.46
9	7	H. L. Baldwin, jr	......do	43.04
9	8	......do	......do	83.26
9	9	George T. Hawkins	......do	145.60
9	10	William J. Peters	......do	226.30
9	11	Ralph Kitchen	Subsistence	136.00
9	12	F. H. Seeley	Traveling expenses	10.50
11	13	Wilson Young	......do	35.74
11	14	Robert Muldrow	......do	38.07
11	15	......do	Field expenses	93.25
11	16	R. M. Towson	......do	72.49
11	17	Hersey Munroe	......do	17.10
11	18	R. H. Chapman	......do	7.02
13	19	W. M. Beaman	......do	5.35
13	20	Van. H. Manning	......do	70.37
14	21	George T. Hawkins	Traveling expenses	61.00
18	22	Hersey Munroe	Field expenses	32.83

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

SEPTEMBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Sept. 21	23	Robert Muldrow	Field expenses	$153.10
21	24	George T. Hawkins	......do	107.50
22	25	A. E. Murlin	......do	50.21
22	26	H. B. Blair	......do	117.48
22	27	H. L. Baldwin	......do	99.70
22	28	H. S. Wallace	......do	150.50
22	29	A. E. Murlin	......do	32.84
25	30	John H. Renshawe	Traveling expenses	85.97
30	31	......do	Services, Sept., 1893	179.40
30	32	Gilbert Thompson	......do	220.20
30	33	H. M. Wilson	......do	203.80
30	34	Pay roll	......do	935.80
30	35	......do	......do	280.40
30	36	......do	......do	127.80
30	37	......do	......do	322.60
30	38	......do	......do	260.80
30	39	......do	......do	393.80
30	40	......do	......do	304.60
30	41	......do	......do	393.80
30	42	......do	......do	280.20
30	43	......do	......do	258.80
30	44	......do	......do	300.40
30	45	......do	......do	226.80
30	46	......do	......do	205.00
30	47	......do	......do	207.80
30	48	......do	......do	253.80
30	49	......do	......do	240.40
30	50	......do	......do	344.20
30	51	......do	......do	192.80
30	52	......do	......do	114.20
30	53	W. C. Cannon	......do	50.00
30	54	Pay roll	......do	187.60
30	55	......do	......do	180.40
30	56	......do	......do	447.20
30	57	......do	......do	194.20
30	58	Hersey Munroe	Field expenses	27.81
30	59	Robert Muldrow	......do	137.90
30	60	......do	Traveling expenses	5.32
30	61	......do	......do	10.86
30	62	V. Schoonmaker	Field material	109.45
30	63	......do	......do	180.50
30	64	F. H. Seely	Services, Sept., 1893	73.40
30	65	H. S. Wallace	......do	130.40
30	66	H. L. Baldwin, jr	Field expenses	63.00
		Total		10,892.08

OCTOBER, 1893.

Oct. 7	1	H. M. Wilson	Traveling expenses	$144.55
7	2	John H. Renshawe	......do	95.23
7	3	George T Hawkins	......do	50.60
7	4	P. F. Sloan	......do	21.40
7	5	Wilson Young	......do	16.48
9	6	J. D. Lincoln	Services, Oct 1-8, 1893	18.26
9	7	H. S. Wallace	Field expenses	93.00
9	8	F. H. Seely	......do	102.40
9	9	George T. Hawkins	......do	97.50
9	10	D. C. Harrison	......do	190.95
9	11	H. L. Baldwin	......do	42.75
9	12	Charles E. Cooke	......do	88.93
9	13	A. E. Murlin	......do	52.80
9	14	......do	......do	65.74
9	15	William J. Peters	......do	215.40
9	16	Cyrus C. Babb	......do	15.00
10	17	H. B. Blair	......do	116.30
12	18	R. M. Towson	......do	154.76
15	19	J. D. Lincoln	Services, Oct. 9-15, 1893	15.98
17	20	Van H. Manning	Field expenses	183.35
17	21	H. S. Wallace	......do	63.00
20	22	Hersey Munroe	......do	49.30
24	23	F. W. Clay	Services, Oct. 1-24, 1893	38.71
24	24	Thomas S. Clark	Traveling expenses	51.75
31	25	Robert D. Cummin	Services, Oct., 1893	134.80

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

OCTOBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Oct. 31	26	F. H. Seely	Field expenses	$73.50
31	27	Charles E. Cooke	do	83.63
31	28	Gilbert Thompson	Services, Oct., 1893	227.40
31	29	John H. Renshawe	do	185.30
31	30	H. M. Wilson	do	210.60
31	31	Frank Sutton	do	134.80
31	32	J. H. Jennings	do	134.80
31	33	Pay roll	do	210.63
31	34	do	do	214.80
31	35	do	do	290.60
31	36	do	do	210.60
31	37	do	do	896.30
31	38	do	do	352.90
31	39	do	do	400.60
31	40	do	do	287.40
31	41	do	do	312.70
31	42	do	do	269.60
31	43	do	do	241.58
31	44	do	do	131.10
31	45	do	do	193.70
31	46	do	do	226.90
31	47	do	do	164.35
31	48	John D McRae	Services, Oct. 1-10, 1893	16.13
31	49	M. Hackett	Field expenses	124.23
31	50	do	Traveling expenses	37.85
31	51	Charles E. Cooke	do	71.22
31	52	John D. McRae	do	57.45
31	53	Pay roll	Services, Oct., 1893	117.90
31	54	do	do	456.40
31	55	George T. Hawkins	Field expenses	212.91
31	56	R. M. Towson	do	98.51
31	57	George T. Hawkins	Traveling expenses	42.95
31	58	J. M. Woodward	do	45.75
31	59	F. C. Wemple	do	15.40
31	60	N. B. Dunn	Forage of stock	7.50
31	61	Joseph M. Springman	do	10.45
31	62	William J. Peters	Field expenses	193.52
31	63	H. L. Baldwin, jr	do	95.55
31	64	H. M. Wilson	do	14.75
31	65	H. Rallston Connell	Services, Oct. 1-21, 1893	40.65
31	66	Pay roll	Services, Oct., 1893	328.70
31	67	do	do	455.80
31	68	James L. Johnson	Traveling expenses	31.80
31	69	Pay roll	Services, Oct., 1893	101.10
31	70	do	do	181.89
31	71	H. L. Baldwin, jr	Traveling expenses	49.97
31	72	do	do	35.15
31	73	C. G. Van Hook	do	18.60
31	74	Hersey Munroe	Field expenses	22.30
31	75	E. A. Hagerty	Forage of stock	20.00
		Total		10,477.16

NOVEMBER, 1893.

Nov. 6	1	East Tennessee, Virginia, and Georgia Ry.	Transportation	$3.00
6	2	William C. Clark	Services, Nov. 1, 1893	2.00
6	3	G. E. Hyde	Field expenses	42.73
8	4	A. E. Murlin	do	100.42
8	5	do	do	19.47
8	6	John H. Renshawe	Traveling expenses	148.51
8	7	D. C. Harrison	do	50.05
8	8	William H. Griffin	do	50.05
8	9	George T. Hawkins	do	38.75
9	10	Sam Feland	do	17.85
9	11	B. Peyton Legaré	do	38.75
9	12	C. G. Van Hook	do	16.05
10	13	A. B. Searle	do	37.30
10	14	Van H. Manning	do	10.00
10	15	do	do	38.75
10	16	Robert Muldrow	Field expenses	76.02
10	17	D. C. Harrison	do	103.45
14	18	Van H. Manning	do	96.16
14	19	do	Traveling expenses	36.85
14	20	R. M. Towson	do	38.25

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

NOVEMBER, 1893—Continued.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Nov. 14	21	Duncan Hannegan	Traveling expenses	$17.25
14	22	John Boler	do	19.40
14	23	do	Services, Nov. 1-5, 1893	5.83
18	24	William J. Peters	Traveling expenses	39.85
18	25	do	do	21.31
20	26	A. Buford	Services, Nov. 1-20, 1893	40.00
22	27	H. S. Wallace	Traveling expenses	15.25
22	28	do	Field expenses	77.50
22	29	F. H. Seely	do	138.50
22	30	R. M. Towson	do	89.02
22	31	O. G. Ballard	Hire of horse	68.00
24	32	Hersey Munroe	Field expenses	34.49
24	33	H. B. Blair	do	247.35
24	34	M. Hackett	do	194.20
24	35	William J. Peters	do	152.00
24	36	Jas. C. Cook	Traveling expenses	41.98
24	37	W. C. Frye	do	18.50
24	38	F. H. Seely	do	54.51
24	39	Nat Tyler, jr	do	39.85
24	40	W. T. Walker	do	16.20
24	41	Alan M. Johnson	do	47.50
24	42	J. R. Ellis	do	19.80
24	43	Pay roll	Services, Nov., 1893	867.40
29	44	do	do	636.00
29	45	Gilbert Thompson	do	220.20
29	46	Pay roll	do	1,940.22
29	47	do	do	1,966.15
29	48	do	do	143.73
30	49	A. D. Murlin	Services, Nov. 1-20, 1893	26.66
30	50	Frank Monroe	do	20.00
30	51	A. E. Murlin	Traveling expenses	135.85
30	52	Basil Duke	do	37.35
30	53	Gilbert Thompson	do	111.66
30	54	H. S. Wallace	do	17.87
30	55	do	Field expenses	17.50
30	56	Pay roll	Services, Nov., 1893	191.67
30	57	H. B. Blair	Field expenses	32.45
30	58	do	Traveling expenses	38.50
30	59	Hersey Munroe	do	20 65
30	60	R. E. Ford	do	12.55
30	61	Alix Brown	do	16.45
30	62	J. J. Fawbush	Forage of stock	46.33
30	63	C. F. Edin	do	43.55
30	64	S. E. Cook	Services, Nov. 1-20, 1893	23.33
30	65	Alan M. Johnson	Services, Nov. 1-19, 1893	16.67
30	66	W. T. Walker	Services, Nov. 1-9, 1893	13.50
30	67	R. E. Ford	Services, Nov. 1-13, 1893	13.00
30	68	Pay roll	Services, Nov., 1893	71.83
30	69	do	do	100.00
30	70	John Cammack	Storage, July 1-Nov. 30, 1893	25.00
30	71	Jas. C. Cook	Traveling expenses	3.00
30	72	A. E. Murlin	Field expenses	93.26
30	73	W. H. Lovell	Traveling expenses	43.28
30	74	G. E. Hyde	Field expenses	113.45
		Total		9,421.56

DECEMBER, 1893.

Date of payment.	No. of voucher.	To whom paid.	For what paid	Amount.
Dec. 7	1	James P. Kelly	Storage, Nov., 1893	$2.00
11	2	H. G. McCall	Forage of stock, Nov., 1893	14.00
11	3	E. A. Hagerty	do	18.67
31	4	J. J. Fawbush	Forage of stock, Dec., 1893	57.40
31	5	C. T. Edin	do	30.00
31	6	Mount Airy Manufacturing Co.	Storage	10.00
31	7	N. B. Dunn	Forage of stock	222.28
31	8	John Cammack	Storage	5.00
31	9	J. B. Carlisle	do	6.00
31	10	F. B. Scott	Services, Dec. 16-31, 1893	25.80
31	11	Pay roll	Services, Dec., 1893	884.40
31	12	do	do	946.30
31	13	do	do	2,375.80
31	14	do	do	1,947.08
		Total		6,544.73

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

JANUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Jan. 2	1	J. T. McGhinnis	Storage	$2.38
2	2	Joseph Marion	......do	8.00
5	3	J. H. Hagerty	Forage of stock	40.00
5	4	Cyrus C. Babb	Field expenses	16.00
15	5	McGhees Cotton Co	Storage	1.46
19	6	Liddon Bros	......do	6.61
19	7	Edward Root	......do	28.45
29	8	H. M. Wilson	Traveling expenses	25.45
29	9	Henry Gannett	......do	32.70
31	10	J. J. Fawbush	Forage of stock	50.00
31	11	J. G. Smith	Storage	4.00
31	12	Pay roll	Services, Jan., 1894	811.20
31	13	......do	......do	954.20
31	14	......do	......do	2,426.10
31	15	......do	......do	2,007.40
31	16	P. H. Christie	......do	155.00
31	17	......do	Traveling expenses	128.58
31	18	C. F. Edin	Forage of stock	30.00
31	19	N. B. Dunn	......do	65.17
31	20	J. H. Hagerty	......do	40.00
		Total		6,832.70

FEBRUARY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Feb. 7	1	J. M. Springman	Forage of stock	$7.50
10	2	Gilbert Thompson	Traveling expenses	115.35
28	3	Pay roll	Services, Feb., 1894	877.60
28	4	......do	......do	866.60
28	5	......do	......do	2,002.58
28	6	......do	......do	2,062.80
28	7	J. H. Hagerty	Forage of stock	40.00
28	8	J. J. Fawbush	......do	50.00
28	9	C. F. Edin	......do	30.00
28	10	H. G. McCall	......do	60.00
28	11	James P. Kelly	Storage	9.00
		Total		6,121.43

MARCH, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Mar. 3	1	N. B. Dunn	Forage of stock, etc	$55.04
3	2	Joseph Marion	Storage	8.00
9	3	H. M. Wilson	Traveling expenses	30.10
19	4	P. H. Christie	......do	30.24
31	5	Pay roll	Services, Mar., 1894	966.20
31	6	......do	......do	2,205.70
31	7	......do	......do	1,109.20
31	8	......do	......do	2,081.10
31	9	N. B. Dunn	Forage of stock	49.50
31	10	J. T. McGhinis	Storage	3.00
31	11	Joseph Marion	......do	4.00
31	12	James P. Kelly	......do	3.00
31	13	H. G. McCall	Forage of stock	20.00
31	14	J. J. Fawbush	......do	50.31
31	15	C. F. Edin	......do	30.00
31	16	J. H. Hagerty	......do	40.00
31	17	J. G. Smith	Storage	6.00
31	18	John Cammack	......do	15.00
		Total		6,706.39

Abstract of disbursements made by P. H. Christie, special disbursing agent, U. S. Geological Survey—Continued.

APRIL, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
Apr. 9	1	H. M. Wilson	Traveling expenses	$35.60
14	2	......do	......do	32.75
30	3	Pay roll	Services, Apr., 1894	986.85
30	4	......do	......do	370.80
30	5	......do	......do	1,197.90
30	6	......do	......do	1,682.70
30	7	J. J. Fawbush	Forage of stock	40.00
30	8	C. F. Edin	......do	30.00
		Total		4,376.60

MAY, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
May 2	1	G. E. Hyde	Traveling expenses	$20.12
2	2	H. G. McCall	Forage of stock	20.00
3	3	J. H. Hagerty	......do	40.00
3	4	N. B. Dunn	......do	49.50
7	5	P. H. Christie	Traveling expenses	19.10
15	6	Jas. McCormick	......do	20.47
31	7	Pay roll	Services, May, 1894	178.80
31	8	......do	......do	1,130.10
31	9	......do	......do	679.95
31	10	......do	......do	1,391.40
31	11	......do	......do	1,097.60
31	12	......do	......do	1,839.40
31	13	J. J. Fawbush	Forage of stock	40.00
31	14	J. H. Hagerty	......do	40.00
31	15	C. F. Edin	......do	30.00
		Total		6,596.44

JUNE, 1894.

Date of payment.	No. of voucher.	To whom paid.	For what paid.	Amount.
June 2	1	G. E. Hyde	Field expenses	$145.75
5	2	N. B. Dunn	Forage of stock	49.50
7	3	H. G. McCall	......do	20.00
19	4	Frank Sutton	Field expenses	85.55
19	5	......do	Traveling expenses	13.98
19	6	J. H. Wheat	......do	9.05
19	7	Robert Muldrow	......do	8.05
30	8	C. F. Edin	Forage of stock	30.00
30	9	J. J. Fawbush	......do	40.00
30	10	N. B. Dunn	......do	43.50
30	11	H. G. McCall	......do	20.00
30	12	J. H. Hagerty	......do	40.00
30	13	J. B. Carlisle	Storage of property	6.00
30	14	J. T. McGhinnis	......do	3.00
30	15	J. P. Kelly	......do	9.00
30	16	J. G. Smith	......do	6.00
30	17	John Cammack	......do	15.00
30	18	Mount Airy Manufacturing Co	......do	10.00
30	19	A. E. Murlin	Field expenses	12.00
30	20	Pay roll	Services, June, 1894	173.10
30	21	......do	......do	436.90
30	22	......do	......do	1,190.55
30	23	......do	......do	1,928.60
30	24	......do	......do	995.50
30	25	......do	......do	915.40
30	26	G. E. Hyde	Field expenses	175.56
30	27	Frank Sutton	......do	83.81
30	28	J. H. Jennings	......do	61.22
30	29	H. L. Baldwin, jr	......do	9.95
30	30	......do	Traveling expenses	19.35
30	31	C. W. Goodlove	......do	20.00
		Total		6,576.32

Amount expended as per abstracts	$434,777.13
Bonded railroad accounts settled at U. S. Treasury	1,315.27
Total expenditures	436,092.40

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, 1894.

PRELIMINARY REPORT ON THE GEOLOGY OF THE COMMON ROADS OF THE UNITED STATES.

BY

NATHANIEL SOUTHGATE SHALER.

CONTENTS.

PRELIMINARY REPORT ON THE GEOLOGY OF THE COMMON ROADS OF THE UNITED STATES.

By N. S. Shaler.

PREFATORY NOTE.

It is intended in the following memoir to set forth in a general way the facts which are known concerning the conditions of roadmaking in this country, so far as they are determined by its geologic and topographic features. In preparing the report the writer has availed himself of information obtained from a number of the officers of the Geological Survey, as well as from various persons who were not in that corps. He is particularly indebted to Maj. J. W. Powell, Prof. T. C. Chamberlin, Prof. C. R. Van Hise, Prof. J. E. Wolff, Mr. W. J. McGee, Mr. Frank Leverett, Mr. Bailey Willis, Mr. G. H. Eldridge, Mr. R. T. Hill, and Dr. J. W. Spencer, lately State geologist of Georgia. Some portion of the information here presented has been gathered by the Massachusetts Highway Commission, a board established by that Commonwealth, to which has been committed the task of a general inquiry concerning the roadbuilding materials which may be used by its people, as well as the business of constructing a system of State roads.

The detailed statement of this report concerning the location and value of road materials in this country could have been almost indefinitely extended by the use of census and other reports. This course has been avoided for the reason that the information thus obtained would have no value, except that of a statistical nature, and would be likely to mislead roadmasters in the choice of materials to be used in their work.

From the statements of this report it will readily be perceived that there is as yet but little trustworthy information in hand as to the relative value and particular distribution of the roadbuilding stones of the United States. It is to be expected that with the progress of the Survey such information will be rapidly gathered and put in shape for public use. Therefore the matter hereinafter presented may be regarded as a preliminary statement, rather pointing the way to inquiry than having of itself a considerable or permanent value.

INTRODUCTION.

All advance in civilization is closely connected with an extension of commercial and social communication. The most extended intercourse—that between the several great lands or continents—is necessarily by the way of the oceans or seas; that between the different divisions of the same area, though here and there it is accomplished by the navigation of lakes, canals, and rivers, is principally effected by land roads. Formerly these ways were altogether adapted to the use of horse vehicles. Of late the work of land ways has come to be divided between railroads and ordinary highways.

The effect of the use of land ways on the development of civilization is evidently great. It is easy to see that so long as men trusted to water communication for their commerce they were to a great extent limited in their dwelling places to regions immediately adjacent to the shore of the sea or to the banks of navigable streams or lakes. Even these methods of intercourse were precarious, as they were much affected by storms and in a large part of the earth by the winter ice. The result is that those peoples which have depended for their commerce upon navigation only have rarely become numerous or attained a considerable economic development.

The effort to establish commerce by land ways appears to have been one of the principal inducements which led to the domestication of the larger beasts of burden. Even before our kine served for milch cattle or for drawing the plow, they were extensively used as pack animals, for which purpose they were fairly well fitted. It seems pretty clear that horses were valued for that purpose long before the saddle became generally used for the conveyance of man. The failure to devise the stirrup until relatively modern times appears to indicate a lack of experience in equestration among the early peoples.

Although the distant land commerce of our own and other civilized countries is now principally effected by railways, and much of the local commerce is accomplished by the same means, the immediate well-being of every community is greatly influenced by the character and condition of its common roads. During the last half century the constructive energy of our people, so far as ways of communication are concerned, has been mainly directed to the extended iron ways; but we have now attained a stage in our industrial development where the attention of our people is again directed to the lesser but equally important routes. In part, at least, this recent interest in ordinary highways is due to a growing sense of the importance of the conditions which favor or hinder the local advantages of our communities. Men are learning that the most available good which the world has to give them is that which lies nearest their doors. A few years ago our agricultural communities were in a state of unrest for the reason that the cheap and fertile land of our frontiers invited the farmer to seek fresh fields and pastures new.

The frontier, so far as it is a land of promise, has now practically disappeared. The Eastern farmer of to-day knows full well that if he betakes himself to the West he must buy such good and easily cultivated land as is to be obtained from thrifty private hands and not from a generous Government seeking to divide a great heritage among its people.

All land transportation routes are, as regards their location, construction, and maintenance, profoundly affected by geological conditions, by the state of the earth over or through which they are made, by the character of the soil or the underlying rock, by the way in which the materials are affected by frost and rain and the pressure of wheels and of the feet of animals, and by the contours which the geological history of the region has impressed upon it. Only by knowing and considering these earth conditions is it possible to build and keep roads of good character at moderate expense. It therefore seems worth while to make some inquiry into the geological conditions of highways and to gather and set forth the knowledge which the earth science has to impart concerning them.

It will be well to approach the subject of highway geology with certain general statements concerning the conditions of the earth's surface which have a bearing on the construction of roads. In the earlier states of civilization all land transportation was effected by burdens put upon the backs of living beings. In the simplest state of commerce the small amount of carriage was effected mainly by packs on the shoulders of men. This appears to have been the way in which the aboriginal traders of this country conveyed their small wares over the land. In the next stage of development, where men have subjugated horses or cattle, the pack animal takes the place of the porter, each beast being able to carry several times as much as a man. Except for certain principal routes this state of internal communication continued in Europe well into the seventeenth century. It was maintained in some parts of this country, in the region east of the Alleghanies, until after the civil war, and it is still in extensive use in the Cordilleras of North and South America.

The wheel, though an ancient instrument, in use in Egypt and neighboring countries more than four thousand years ago, served first for chariots of war and state, and only gradually became an important instrument of commerce in the hands of the Romans. Until that eminently economic people developed the use of the wagon, the sled and the detached roller placed beneath the burden were the only instruments for conveying heavy weights over the land. The road, as distinguished from the unimproved pathway, is thus a relatively modern invention. Like nearly all the other advances in civilization, it brought men into a closer dependence upon the conditions of the earth. As long as burdens went upon the backs of men or beasts the condition of the trail over which the pack-bearers made their way could vary greatly without materially affecting the usefulness of the route; but the use of the wheel imposes a far greater uniformity in the character of the way which is to be traveled. A trail could be laid across country without stirring the original surface and without much attention to grades, and it demanded little repair save that which use gave it. The road, on the other hand, requires labor and skill to make it reasonably traversable, and to bring it into the best condition demands architectural ability of a highly developed kind. The conditions of a good wagonway are such that it may be described as a hard open-air floor extended across a country. Its surface should be as nearly as possible level, and be composed of materials which will give the quality of surface required for the foothold of horses or oxen and at the same time yield as little as may be to the tread of the wheel. Perfectly to attain these conditions within the limits of geologic materials is impossible, yet with skill and the exact application of the means which the country affords it is generally possible to approach very nearly to the ideals of the arts.

OUTLINE OF HISTORY OF AMERICAN ROADS.

Before the settlement by Europeans the indigenous peoples of this country appear to have made little use of the native animals for carrying burdens. So far as known, the only Indians who used pack animals at all were the tribes on the west coast of South America, who had domesticated the llama, a creature which is able to carry a hundredweight for a distance of about 12 miles a day. The extensive and well-constructed roads, the remains of which still exist in Yucatan and the neighboring parts of Central America, may indicate that the prehistoric people of that district had some beast of burden at their command. It is the opinion of archæologists, however, that they were built to serve the purpose of footmen.

Except in western South America and in the region south of the Rio Grande, there were at the time of the first European settlements no roads in this country which were fitted for the use of pack animals. For a time the only way of making journeys was afoot or in boats. Although, as many expeditions show, strong men, with no more provisions than they can carry on their backs, may be able to traverse wildernesses such as originally occupied this continent, nothing deserving the name of commerce can now be effected in that way. Thus it came about that the first extended trade in this country was accomplished by means of boats, which traversed the waterways afforded by the rivers and lakes, a "carry" or portage being made from the headwaters of one stream to those of another. Owing to the fact that the only navigable ways leading into the interior of the continent were at first in the hands of the French, that people had for a time a notable advantage over the British colonies in entering the country and in trading with the aborigines.

For a time the European settlers along the eastern coast, between the Bay of Fundy and Florida—the colonies which became the original States of the Union—trusted almost altogether to the sea and its inlets for their communication. With the increase of population these settlements were pushed back from the shore, so that extended roads became necessary. At first these ways were often developed as trails adapted to saddle and pack animals. The original routes followed the Indian trails or the paths which the larger wild animals made by their migrations, and were little improved by art. Gradually, as the traffic became greater, these lines of travel were made accessible to wheeled carriages. At first this work was done in a very rude manner; afterwards, in cases where the ways were of importance, those who improved them were given the right to take tolls from the people who passed over them.

The earliest stage of pioneering in a frontier country of rude surface and covered with dense woods can be accomplished only by the use of pack animals. In such conditions the outer fringe of population is far in advance of the carriage roads, and those outposts can be kept in communication with the settled country only by the primitive means of conveyance. In this stage of development the ways are laid out with little or no consideration. They commonly follow the sides of streams, for the reason that these routes afford the least difficulties. In the colonization of Kentucky the first paths to the east followed, as far as possible, the courses of the rivers, and often made use of their beds, which were, of course, free from timber. Those streams were selected whose floors were shallow and smooth enough to afford a footing for beasts of burden. Thus, the trail was led up the waters of the Shenandoah and Roanoke, thence over the Alleghanies to the headwaters of the New River; thence to the Tennessee, and by its tributaries to Cumberland Gap. Beyond that pass the original paths again followed the brooks to central Kentucky. Even when the roads were made passable for rude wagons, they lay to a great extent in the beds of streams, or along their shores, that were bared at low water. When better roads were built they followed as nearly as might be the original courses of the route, for the sufficient reason that the settlers had grouped themselves along these paths. Thus it came about that the positions of the main highways of the Appalachian district were fixed, not by design, but by a chapter of accidents, in which the contour of the country, as determined by its geological structure and the sites of the old Indian and animal trails, which depended on the natural features, were guiding conditions.

The adjustment of the pioneer routes to the geological structure of the country is also well shown by the careful manner in which they were devised so as to escape the deep canyons of the James and the Kanawha, which lie almost in the direct path from Virginia to Kentucky. The first generally traveled route was the one above noted, through Cumberland Gap. A second, though on the whole a later-used route, was by the valley of the Potomac to the headwaters of the Ohio, and thence by boat down that stream. A few immigrants used a path across from the headwaters of the James to the valley of the Kanawha, below the point where its gorge opens into a wide valley. The canyons of this river and those of the streams in the district are due to the peculiar structure of certain of the Carboniferous rocks. Thus the geological conditions of the area greatly hindered the access of population to the first fields of settlement which were established in the Ohio Valley.

The pack saddle in the Appalachian district was originally borne by horses. As the use of mules extended, it became customary to make them serve in this work. Still further on in the history of the country, bulls and oxen were often turned to this use. It may, in general, be said that the pack train was the effective pioneer mode of transportation during the time when the frontier was passing beyond the Alleghanies. Entering the flat lands of the Mississippi Valley, where navigable streams abounded, and where the character of the surface made it relatively easy to construct wagon roads, wheeled vehicles speedily displaced the pack train. It was not until the miners began to enter the mountainous portion of the far West that the pack saddle again came into general use.

So long as land transportation is carried on by pack trains, the geological conditions of a country affect the history of the roads in only a secondary way. The trails are laid across the surface on the most practicable lines, and no effort whatever is made to provide pavement. In fact, for the use of beasts of burden, where the weight is carried on the back, it is better that the road be not paved. The inconvenience which may be encountered from the mire that is apt to occur where there is no pavement is less great than that which results from the wearing of the animals' feet on a very hard surface. Even where the beasts of burden are well shod the damage which may arise from continuous treading on an unyielding surface is great. Nevertheless, as may be seen by the study of the history of our American roads, the wheelway has, in general, its course determined by what was originally only a trackway. Here and there, both in this country and in Europe, we may trace the narrow though often deep furrows of the old pack-train paths cutting over the hills on slopes too steep to be faced by wheeled vehicles. Thus, laid out rather by accident than design, these early trackways or wheelways often became the paths of considerable streams in times of heavy rains. South of the drift-covered belt in this country, especially in the regions where the soil is rather clayey, the roads, by water action, have often become deep natural ravines; sometimes, indeed, in the Southern States, they have attained a depth of 30 feet or more in less than a century of use.

In the Old World the lines of the ancient trackways are much more conspicuous than in this country, for the reason that in the original seats of civilization pack trains served the people for a thousand years or more before the use of wheels was adopted. Except in the Spanish States of America, the use of the pack saddle was generally discontinued within a century after the settlement of the continent began. In fact, we may use the speed of its' disappearance as an index of the enterprise and consequent commercial prosperity of a newly settled country. Thus, in New England the pack saddle appears not to have been used after the first century of its occupation, while in Mexico four centuries of development have not served to advance the people to a point where they have put aside this ancient instrument of conveyance. In general, it may be said that the English people have been very intolerant of the pack-train transportation, while the Latin folk, particularly of Spanish origin, have shown a disposition to cling to this primitive method of maintaining commerce. It is a noteworthy fact, however, that while the English-speaking people demand wheeled vehicles, and are prone to build roads over which they can journey, they have not, on the whole, been as good builders as the folk of southern Europe, who directly inherited the Roman tradition of highway construction.

At an early stage in the construction of American roads it became a general custom to support the wheels in wet parts of the way by means of cross-laid poles placed close together. In many cases miles of important roads were thus improved. This system received the name of "corduroy," though when thus prepared the term "laid roads" was applied to them. Those who have journeyed over these ways need not be told that they are extremely uncomfortable. These irregularities of the surface cause a sharp up-and-down movement of the wheels, and the sticks, soon becoming stripped of their bark, are very slippery to the horses' feet. Hence efforts were soon made on the better class of roads to provide against these evils by squaring the timbers and spiking them to bed plates. Out of this improvement probably came the characteristic American plank road, which, from the middle of this century till about 1870, was commonly in use in regions where timber abounded.

Although the plank road, when first made, is an admirable way, fulfilling all the required conditions, it soon wears out. The grain of the wood being parallel to the wearing surface, the timber soon breaks into shreds. Therefore another adaptation of the wood pavement was made, that known as the "wooden-block" pavement. For a time this system was very popular both in this country and in northern Europe. In the Old World it is still well esteemed, but in this country it has gone out of use. The reason for the difference is probably to be found in part in the unwillingness of our people to take a high degree of care in the repair of their ways, and in part it is probably due to the fact that American vehicles are driven at a higher speed than those of the Old

World, and thus pound the way in a more violent manner. Something of the effect may be due to differences in climate.

Yet another essay in the use of timber for road construction was made, according to the observations of the writer, in the northwestern part of this country during the last decade. Wood of any kind was shredded into a mass of narrow, rather thick shavings, commonly known as "excelsior" from the fact that it is used for making cheap mattresses which were sold under that name. This material was applied to the streets as a coating, about a foot in thickness. Although these excelsior roads were dry, elastic, and tolerably smooth, in every respect a great improvement on the mud which they replaced, they were rather costly, unenduring, and absorbent of filth. The system is interesting only as an index of the inventive motive of our people and as probably the last term in the series of wooden pavements.

METHODS OF USING STONE IN ROADBUILDING.

Wheeled vehicles were used for ages before it seemed to have occurred to men to do any particular work toward insuring a better foundation for them than the soil afforded. It may in general be said that although wheeled carriages are of very ancient date, their general use in commerce is less than two centuries old. The Romans made a considerable use of wagons on their great paved ways, but notwithstanding all the writing about Roman roads, the extent of these constructions was very limited, and almost all the inland commerce which then existed was carried on by means of pack trains. Thus, in England during the period of the Roman occupation, which endured for four centuries, the total length of good roads built was but a small fraction of that which now exists. It is probable that the ways made passable for wheels by the Romans in all the lands they occupied amounted to an aggregate of 10,000 miles in length, or about one-third the extent of the existing highways in the State of Massachusetts.

So long as wheels were left to deal with the natural surface of the earth the advantage which carriages afforded over pack trains was relatively small. The effect of the rotating disks is to cut through and to shear aside the soil materials in a way which leads to a partial locking of the wheels by the detritus. The very quality which makes the soil coating a suitable material in which the plants may search for food prevents its serving as a hard floor, such as is required for the best service of wheels. It may, indeed, be said that the better the soil the worse the way which it will afford to loaded vehicles. When first assailed by wheels the natural earth offers, through its coating of roots, which ordinarily lies just below the surface, some measure of defense against the disturbance. As soon, however, as this coating is removed or worn through, except at times when the earth is very dry, the wheels inevitably cut down below the true soil layer to a point where their further descent is arrested by a hardpan or other stony material.

The great Roman invention in roadmaking consisted of paving the way with flat blocks of stones strong enough to uphold the wheel. This form of pavement by means of stone blocks appears to have begun with the floors of the temples and other buildings, these floors being gradually extended so as to include a plaza and the streets of the city. Thence the extension into the open country in ruder workmanship was naturally brought about. Unfortunately the Roman system, though making a good road, is applicable in but few parts of the world. Only the few harder varieties of stone, such as the traps and the granites, are suitable for such use, and these are found only here and there, and usually in countries of rather limited agricultural value. Moreover, this method of constructing roads, even where the materials lie near at hand, is very costly; hence it came about that, until the middle of the last century, the highways of most places outside of the great cities were almost impassable to burdened vehicles except during the dry and the frosty seasons of the year. Even this moderate service was obtained at the cost of incessant labor on the roads which were much traveled, and of great waste from the need of repair of vehicles and from the excessive number of animals required to draw them. On such roads it was the custom to have the highway right very wide, so that the drivers could turn this way or that to escape the deep ruts worn by those who had gone before.

With Macadam's invention a new path was opened in the construction of roads. He discovered the fact that almost any stone of sufficient hardness to resist the tread of the wheels would, when broken into small bits and placed on the road as a coating of sufficient depth, in a short time harden under the travel. To Macadam we owe this interesting discovery concerning the process of cementation and matting, which causes bits of stone to become bound together when acted on by a roller or by wheels, until they form a firm, set mass. The peculiar advantage arising from the use of this principle consists in the fact that roads can in this way be constructed at a relatively small expense as compared with pavements made of blocks, and that the work can be done in many regions where suitable blocks for paving can not be obtained.

As yet the natural history of the macadam process is not well understood. It seems, however, to be due to the fact that almost all hard stones, when freshly powdered, exhibit more or less of the action which we recognize in what is known as water cement; that is, the powdered material sets into a firm mass.

If a mass of broken stones is allowed to lie with the fragments resting on one another, no evident trace of cementation takes place; but if the materials be repeatedly traversed by heavy wheels, or, better, by a roller of great weight, then as soon as the mass of broken stone is wet the cementation sets in. This fixing of the bits of stone together has been attributed in part to the interlacing of their rough faces when they are driven together. Experiments seem clearly to show, however, that the effect is mainly due to the fact that the friction of bit on bit produces by the grinding action a sufficient amount of powdered rock to form the required cement. The binding strength of the cement varies much with different species of stone, but it exists in some measure with them all.

In some forms of detritus the cementing quality of broken stone is found to exist also where the powdered state has been brought about by natural action. Thus, in many places within the region affected by the ice of the last glacial period, we find gravels composed of rocks which, though broken up, have, on account of the overlying deposits, been protected from decay, their immunity from this action being shown by their prevailing blue color. It is a well-known fact that such materials will cement together when placed upon a road and sufficiently rolled. On the other hand, the ordinary decayed, and therefore brown or reddish, gravels can not by any process be made to bind together. The fact seems to be that no decayed stone retains the capacity of cementation when powdered, though in some few cases, where the material is charged with iron oxides, it may, by the cementing action of the oxides, undergo a certain binding.

Experiments have shown that no ordinary flinty gravels free from iron oxides can be made to form a firm roadbed. No amount of rolling will produce the quantity of powdered rock necessary to unite the fragments together. Moreover, such powder as may be made has a relatively slight cementing power. On the other hand, if a considerable part of the pebbles be of limestone, rolling—either that intentionally done by machines devised for the purpose or that done by the wheels of vehicles—may produce enough cementing material to bind the mass, provided the pebbles are not too much decayed. In certain of these gravels, particularly in those transported by rivers, which often constitute a considerable part of alluvial plains, the action of decayed vegetation has led to the deposition of much iron oxide along with the pebbles. In many cases such deposits are firmly cemented in the places where they are found. When broken up and placed upon a road, the action of the rain water will bring about a recementation, so that these materials often make excellent road metal. Even where such gravels are not bound together in the bed, the pebbles will often unite when placed upon a road and well rolled.

Still further, we may note the fact that pebbles, particularly where they are of large size, even though they can not be made to cement in their natural state, will do so when broken into bits, for this process exposes undecayed surfaces from which the powder may be worn by the rolling action of wheels. It thus appears that there are three methods of applying Macadam's invention: by breaking stone taken from the quarry, by using stone broken by natural processes and not decayed, and by rebreaking pebbles which in their natural state can not be made to unite by the cementing process.

RELATIVE VALUE OF ROAD STONES.

Recognizing the fact that for general use a firm roadbed at moderate cost can be made only by the method of Macadam, the question next arises as to the relative value of the different kinds of rock which may be applied to this use. It may be noted that road stone needs to have two qualities: the material must be sufficiently hard to resist the action of the wheel, and the powder of the rock must have enough cementing quality to bind the fragments together into a firm waterproof mass. If the rock be too soft, the wheels will grind it into a powder, which blows or washes away, so that the covering of the road is soon lost; if the cementing action be too slight, the stones will be kicked or pulled out by the horses' feet or pushed aside by the wheels, so that the roadway comes to be strewn with rubble.

Experience shows that the binding power of powdered rock is usually so great that, except in certain of the flinty stones, we may trust the cementing action of the dust produced in rolling to hold the bits together. It is otherwise, however, as to the hardness which is required to resist the crushing action of the wheels. Here the variation is through a wide range. Most rocks are so affected by the tread of wheels that they are quite unfit for road stone, or at most are to be taken only where better material can not possibly be obtained. To understand the nature of the hardness of a rock it is necessary to note that it depends on two features: first, the resistance to disruption offered by the crystals or fragments of which the rock is composed; and second, the strength of the materials which bind these units together. It will thus readily be seen that the conditions determining the endurance of each bit of a macadam road are very much like those which affect the whole coating. As this matter is of much importance, it naturally leads us to some consideration of the structure of rocks.

In the first stage of the formation of ordinary rock, that in which materials composing it are laid down on the floor of a water basin, the mass is made up of fragments which in time become more or less cemented together. In some cases the bits are hard, as when they are composed of quartz feldspar, magnetic iron oxide, etc. In other cases, as where the fragments are of shells, coral, or other limestone materials, the bits are relatively soft. In none of these groups of rocks made up of fragments are the cementing materials likely to be strong, so that if the material does not give way on account of its general softness, it is usually ill adapted for road purposes, because the mass readily breaks up. Hence it comes about that the rocks which remain in the state in which they were first brought together and consolidated on the ocean floors are rarely good for roadmaking.

When such rocks as are above described become deeply buried beneath later accumulations, and are thus subjected to heat, and particularly where they are much compressed, as in mountain building, their materials are taken to pieces and recomposed in the crystalline form. In this state the rocks become harder, or at least more dense, than they were before; limestones are changed to marble, the loose-grained sandstones to quartzite, while the clays are often altered into crystalline rocks, such as gneisses; and a yet more complete change may, it is believed, metamorphose some of the sedimentary rocks into granites, in which the chemical composition of the mass is the same as it was in the original fragmentary rock, but the substances are arranged in crystalline order.

Such changes as those last noted may occur without the materials composing the rock being reduced to the molten state; but it often happens that the rocks composing the earth's crust are, by volcanic heat, brought into the fluid state and forced up into crevices of the overlying deposits, where, on cooling, they form dikestones. In other cases they are poured forth from volcanic vents in the form of lava, which in time cools down, forming rocks of varied hardness. As these melted rocks harden—a process which generally goes on slowly—their materials commonly assume a crystalline form, and take on a texture which is usually much denser than that of rocks which have never been molten.

All rocks, particularly those which were formed near the surface of the earth or have been brought near the surface by the continuous down-wearing of the land, are subject to change by the action of percolating waters, such as are continually moving through the crust of the earth. We readily note these alterations in the features which mark the decay of stones, but they are equally apparent to the petrographer in more deeply buried and apparently unchanged materials. These alterations considerably affect the strength of rocks, sometimes converting those which were originally fitted for roadbuilding to a weak and, for that purpose, useless state.

In general, it may be said that the volcanic rocks, the dikestones and large crystalline masses, and the superficial lavas, are the best fitted for roadmaking; and of these the material known as basalt is much the best, though there are other groups of these once-molten rocks which are very well suited for such work. Usually the lavas which have cooled in fissures are stronger than those found on the surface of the earth, and this for the reason that when confined between walls of rock the lava has generally been subjected to great pressure, which has caused it in cooling to become a firm, set mass. In the lavas poured out on the surface of the earth the presence of large and small crystals, glass-banded structure, etc., often diminishes the homogeneousness of the stone.

DISTRIBUTION OF ROCKS SUITABLE FOR ROADMAKING.

Although the distribution of such rocks as we are considering depends on many conditions and is a matter of much detail, it may in general be said that they have a grouping which is related to the character of the surface of a country, and this for the reason that the topography of any land depends upon the geological accidents which have affected the earth beneath it. We may, therefore, in a general way, note the following features in the distribution of the rocks suitable for making high ways.

In the regions of broad plains, such as are found along the southern coast-line of this continent and in the Mississippi Valley, we almost invariably find the underlying rocks little changed from their original state of water-made sediments, and the strata of which they are composed lie in a nearly horizontal position, indicating that they have not been affected by mountain-building forces. In such areas dikestones or lavas rarely occur.

Quartz, when it is found, as is sometimes the case, in large veins in which it has been deposited from water at depths below the original surface, often affords a tolerable material for macadam purposes. Owing to the very angular forms which the material assumes when crushed, it mats well together. The bits, however, are not really cemented into a mass, for the dust, unlike that from most other rocks, does not form a binding cement. Moreover, under the pressure of wheels and the beating of horses' feet the material passes rapidly into the state of fine sand, which is blown or washed away. Roads of this material rarely attain a very smooth state, and they wear out rapidly. On this account the vein quartzes are likely to prove of a secondary value in roadmaking.

Quartzites are rocks which were originally sandstones, the fragments of which have to a greater or less extent been dissolved and recemented into a firm mass. The nature of quartzites varies greatly. They often afford useful roadstuff, that which may be reckoned as of a second order of value, and are of much importance where better material is not to be had. Both quartzite and quartz are of importance in roadmaking in the Piedmont district of the southern Appalachians, where most of the other rocks which appear at the surface are generally too decayed for such use.

Another variety of siliceous material which is often very serviceable is known as chert. It consists of quartzose material which has been segregated in beds of limestone rock. When the limestone decays and is washed away, the cherty matter is often left in a rubblelike mass. In many cases the material verges into quartzite and is indistinguishable from it. The cherty residuum arising from the decay of limestone is of value in roadmaking in the southern portion of the Appalachians and in other portions of this country beyond the glaciated field, and also in some of the States of the Northwest where the amount of erosion accomplished by the ice-sheet was relatively small, so that the rocks which had decayed before the glacial time were not altogether removed.

Limestone rocks, though they vary considerably in hardness, are in general much too soft for economical use in roadmaking, provided any other more suitable material can be obtained. The variety of such stone which is known as dolomite commonly affords a better rock than calcite, or ordinary limestone. Thus the beds of the Knox dolomite in Virginia, Tennessee, and the neighboring States generally afford a more enduring material than do the Silurian limestones of central Kentucky. Where the lime is commingled with clay the effect is generally to improve its value as road material; where the mixture is of sand and the mass is an arenaceous limestone, it is generally poor road stone.

Although the limestones must be placed rather low in the scale of rocks fit for use in roadmaking, their wide distribution, particularly in the Mississippi Valley, where the variety of materials for such use is small, gives them a great economic importance. They have for a long time been extensively used in Tennessee, Kentucky, and Ohio, and are beginning to be brought into service in the more western States. It is likely that in the next century they will serve in the construction of more miles of road than all the other kinds of stone which this country affords. It is therefore worth while to note that, where the surface of a limestone road can be covered with iron ore the firmness of the mass is much increased. It may indeed be said that a coating of such ores, which are readily accessible in many parts of this country, adds greatly to the endurance of the way. Wherever rocks of the Clinton age are accessible they are generally found to contain one or more beds of iron ore, which, even where it is unfit for making iron, may serve, along with limestone, in roadmaking.

In the natural processes by which rocks are broken into bits, as by glacial action, by streams, or by the beating of the sea on the shore, pebbles are often formed. These fragments are harder than the rock from which they are made, for the reason that all the softer material has been worn out in the rough usage to which it was subjected. So far as solidity is concerned, the pebbles of any district generally afford the best roadmaking material which it contains.

The general unserviceableness of gravels for roadmaking is due mainly to the fact that the surface of the bits is smooth, so that the mass will not mat together in the manner of broken stone. There is, moreover, no undecayed rock dust between the fragments to serve as a cement; and even if there were such a binding material, it could not effectively fasten to the polished surfaces. Therefore, in almost all cases where it is desired to make a good and enduring road of gravel, the binding of the material must be provided for in one of two ways: the pebbles must be broken by crushing machines into yet smaller fragments, or a "binder" must be provided by using some firm cement.

In certain cases, particularly where the pebbly matter of a gravel deposit is to a greater or less extent composed of limestone, a considerable amount of iron oxide has been gathered in the mass. This effect is due to the tendency of water which contains iron to lay down that substance and to take lime in its place when the opportunity of so doing occurs. These ferruginous gravels are commonly found in a somewhat cemented state, and when the material is broken up and put upon roads it again cements, even more firmly than in its original state, often forming a roadway of very good quality—smooth, hard, and impervious to water.

Certain gravels of the nature above described which are remarkably well fitted for roadmaking occur in the low-lying lands of western Kentucky, and probably in the neighboring States. They are known in commerce as Paducah gravel, from the fact that they have been considerably exported from the district about the town of that name.

In general, the clays, though often used in repairing roads, are totally unfit for that use. Each year much vain labor is expended in this country in the hopeless task of repairing roads with this material. In certain rare cases, where old nonplastic clays of a firm nature are obtainable, the material, when exposed to the air, will set in a way which makes it tolerably firm, yet the road surface thus formed is readily worn by the wheels into dust, which is washed or blown away.

The only fit use of clay for roadmaking is where it is burned in the form of bricks, which are carefully laid on some form of firm bedding and with the interspaces so filled as to prevent the penetration of water. In this burned condition the particles of the clay are partially fused, so that the mass has in good measure the firm, knit quality of those rocks, such as traps, which have cooled from the molten condition.

The other product of the natural disintegration of rocks, sand, may be dismissed with the brief statement that it is totally unfit to afford a bearing surface for wheels. It is true that when completely wetted, as on a flat beach which has just been bared by the retreating tide, the sand grains may be held together in a tolerably firm way by capillarity, due to the presence of water between small fragments, but this effect is lost with a small amount of drying, after which the mass resists the progress of the wheel in a very obstructive way.

In the mountain-built countries the rocks, owing to the pressure to which they have been subjected through the forces which led to the flexing of the strata, are generally very much harder than in the region of the plains. The limestones are likely to be changed to crystalline marble, though even in this state their softness makes them still essentially unfit for use on roads. The clay slates, and even the sandstones, may here be found sufficiently consolidated for use in road construction, though even when thus changed they do not afford materials of much value.

In mountain building, the conditions which lead to the formation of dikes and of other masses of rock which have consolidated from a fluid state, as well as of the hard veinstones, are commonly brought about. In most cases, however, these masses do not attain the surface of the earth, or at least the surface which existed at the time the uplifting took place. It is only when the mountains have been subjected to much down-wearing that the originally deep-lying zone where the dikes and other igneous deposits were formed becomes laid open to the day. Thus, in the Alleghany and Cumberland section of the Appalachian Mountains, elevations which have been formed in relatively modern times, dikes are rarely to be traced, while in the Blue Ridge or eastern section of that system, whose ranges were formed in very ancient times, the down-wearing has disclosed very numerous masses of this nature. Thus again, on the island of Cape Ann, which has an area of less than 20 square miles, nearly four hundred lava-filled fissures have been traced, though owing to the drift and soil-covered character of the area these intrusions are disclosed only along the coast-line. Over a considerable part of New England such dikes could probably, on sufficient examination, be traced to the number of one hundred or more on each square mile of area.

The facts before noted make it plain why the regions occupied by ancient and worn-down mountains most abound in high-grade road-building materials. It is to these districts, indeed, that we must look for the best sources of supply of the rocks which are best adapted for road construction.

Owing to the peculiar geological work done during the last great ice epoch, when a vast glacial sheet lay upon and flowed over the northern and eastern surface of the continent, a large part of our land has been furnished with a peculiar class of materials suitable for road-making. The origin of this supply is as follows: As the glacial ice crept to the southward it rent great quantities of stone from the bed-rocks. These materials were borne southward, either contained in the slow-moving ice or hurried along by the violent currents of water which swept forward to the margin of the field. These torrents probably were impelled by the pressure of the overlying ice, which was often a mile or more thick, and which therefore forced the water onward with great energy. Thus impelled, the under-ice streams were able to bear toward the margin of the glacier great quantities of stone.

In the Appalachian district the effect of glacial action on the supply of road materials is only here and there of economic importance, for in most parts of that field the glacial waste lies on hard rocks which are suitable for roadmaking. But from the Hudson westerly to the Mississippi, the movement having been from the region of hard rocks north of the Great Lakes onto the soft rocks of the States which lie to the south of those basins, the effect has been to import into the last-named district bowlders and gravel of a quality which is better suited to roadmaking than any of the native varieties of stone. Even in its poorest form this glacially transported material is usually better than that which can be had from the underlying rock.

The original range of the glacial gravels has been here and there greatly extended by the streams, which, flowing southward beyond the drift belt, have often carried quantities of the hard detritus for many miles beyond the limits of the ice-field. Thus the Ohio River, the line of which was touched by the glacier only at its headwaters and at Cincinnati, has conveyed quantites of drift gravel all the way to its junction with the Mississippi.

Where the glacial waste is composed of fine materials, as is the case throughout the greater part of the field which it occupies, the detritus rarely has any value for the roadmaker's use. Where, however, fragments abound not smaller than a man's fist, we are likely to find a store of rock which will, when broken in the manner of macadam, serve well in roadmaking. The utility of these materials is increased by the fact that each pebble or bowlder has been well tested for strength by the rude usage which it has met on its journey in or beneath the ice. Except where affected by recent decay, which commonly has not been great, these pebbles are generally sound enough to be of service in highway construction.

In the glaciated districts, and more particularly near the margins of the old ice-fields, there are apt to be numerous hillocks or more extensive masses of angular gravel, which have been well described by Prof. T. C. Chamberlin.[1] In a recent letter to the writer, Professor Chamberlin calls attention to these deposits as sources of roadmaking materials which may often prove of great value where suitable bedrocks are wanting, and even where the other forms of glacial detritus are unfit for such use.

Glacial deposits containing pebbles or bowlders which may afford good roadbuilding material abound in the northern part of Illinois and Indiana; they occupy the greater part of Ohio and western Pennsylvania, and occur in several States of the Northwest in sufficient quantities to serve an important use. As yet, however, they have not been made the subject of deliberate inquiry from the point of view of the roadmaker, and therefore can not be described in a detailed way.

A large part of the pebbly waste which may be made to serve for highway construction in the Western States is bedded with clays and sand, the mass at first sight promising little of value. Experience in the washing of other gravelly deposits proves, however, that by means of simple appliances the pebbles can at a small cost be parted from the useless material. The expense of this process may be accurately judged by work of the same kind which is done in obtaining those iron ores where the bits of ore are scattered in a mass of clay. In Alabama, where at the present time large quantities of ore are thus prepared, experience shows that with the pebbles constituting one-fourth of the mass the cost of the product need not exceed 50 cents per ton. Although this process can not profitably be applied in districts where good trap

[1] Hillocks of Angular Gravel and Disturbed Stratification; Am. Jour. Sci., Vol. XXVII, pp. 378–390, New Haven, Conn., 1884.

rock lies within, say, 100 miles by railway transportation, it will fit the conditions of a large part of this country.

The process above noted as accomplishable in an artificial way is brought about in a natural manner by the action of rivers. It may be assumed that in any country where pebbles intermixed with clay and sand occur in considerable quantities, masses of pebbles will be found in the stream beds or under the alluvial terraces which lie on either side of the existing channels. It must not be assumed that because deposits of such gravel are not visible a sufficient supply does not exist. The material can generally be obtained by dredging from the stream bed in the manner in which phosphate pebbles are removed from the Peace River in Florida, or by excavations made in the alluvial plains. Such sources of supply of road material are destined to be of great importance in almost all parts of the Mississippi Valley.

In those parts of this country which lie to the south of, or beyond, the glaciated districts, and where there has long been a considerable rainfall, the rocks exposed to the action of the weather have decayed by a process of leaching, which in many cases has removed hundreds of feet of strata from the surface of the country. As this process of decay goes forward the rocky matter is removed in proportion to its solubility. Thus, concretions of cherty matter which a bed of limestone may have contained often remain on or near the surface of the earth when all the rest of the deposit has vanished. In the Southern States we not infrequently find this residuum forming a layer many feet in thickness, the fragments being so much harder than the other available rock of the country that they are valuable as sources of road material.

In general these fragments of a flinty nature, derived from the rocks which have been dissolved away from the face of the country, lie in a relatively thin sheet, which is spread in a broadcast manner. Not infrequently, however, we find places where recent or ancient streams have washed over the material, taking from it the clay and sand with which it was originally mingled and leaving the mass of fragments in a condition well suited for use as macadam stone. In many cases the bits are much affected by decay, but when broken they may often be of fair service in roadmaking.

The residual deposits above described are generally found only on the surface of districts which are underlain by tolerably compact rock of considerable age. The reason for this is that only those rocks which have undergone a certain amount of metamorphism are likely to contain the siliceous parts which resist decay in the manner above alluded to. The principal exception to this general rule is found in the concretions of lime phosphates, which, as elsewhere noted in this report, plentifully occur in various relatively modern strata in the southern portion of the United States.

It should be observed that, except where concentrated by streams, the hard waste derived from rocks which have been leached away is generally hidden from view by the soil coating. The earthworms, ants, and other animals which live under ground have the habit of bringing up the fine materials from the interstices of the fragments contained in this soil and depositing this small-grained detritus on the surface. The plants contribute to the same result, and the effect of this combined action is generally to make and keep an ordinary soil layer above the hard bits. The presence of the layer of cherty fragments can often be recognized in the gullies of plowed fields, and along the streams, where they are not bordered by alluvial plains.

In those parts of the country where tolerably good roadbuilding materials can be had from other sources, the residual cherty deposits arising from the decay of rocks are usually not worth the attention of roadmasters, but in many regions where there are no other sources of supply it may be worth while to search for these accumulations, and even to separate the hard fragments from the clay and sand by washing machinery, as is elsewhere recommended in the case of some of the glacial pebbles of the Mississippi Valley.

It occasionally happens that the process of erosion and deposition leads to the formation of deposits having a wide superficial extent, the materials of which are tolerably well suited for roadbuilding purposes. In most cases beds thus formed become covered by other strata and are therefore accessible only by mining, a process which is too costly for the needs of roadbuilding. In some places, however, as at Steep Brook, Mass., these accumulations of ancient detritus can be won by open cuts. At the last-named locality there is revealed by the uptilting of the Carboniferous strata a large quantity of decayed granitic rock, which was swept in Carboniferous times into a basin, forming beds which have locally a thickness of 20 feet or more. As this mass is composed of feldspar crystals and some quartz, it is fairly well suited for constructing roads, but as it is also useful as a fire clay it is not low enough priced for highway construction.

It occasionally happens that detritus of the older rocks having a quality suitable for roadmaking, being of relatively recent origin, has not been covered by later-formed strata, and thus lies as a broad sheet occupying an extended area of the earth's surface. This is the case with the Lafayette formation, which has been well described by Mr. W. J. McGee. The Lafayette beds occupy a large area—about 700,000 square miles—of the plains which surround the southern extremity of the Appalachian Mountain system. They are to a great extent composed of the débris from crystalline rocks which occupy that area. In general, these beds have a constitution which makes the roads constructed upon them of an excellent quality. Without the addition of other materials, they are often firm and smooth at all seasons, and in places they resist the destructive action of the frost. They afford the best natural roads in the Southern States, except those which lie upon the Ohio shale of Devonian age. With a little care the roads on this formation can generally be maintained in passable condition.

BLOCK PAVEMENTS.

In former ages it was the custom to pave highways with blocks of stone. The more important of the Roman ways, the ruins of which are traceable in southern Europe, were thus paved.[1] In modern times the same method of construction is often followed, but it has become limited to routes which have an extraordinarily heavy amount of traffic. For ordinary roads its place has been taken by the macadam system. In the Telford modification of the macadam system provision is made for a lower level of construction, which, as would appear from the ruins, is somewhat like that which the Romans adopted for the traction level of their roads.

In the modern limitation of its use the Roman pavement may be regarded as appropriate for only the more important city streets, and for only such of these as for one reason or another can not be maintained with asphalt or brick coverings. The excessive noise and the wear on vehicles which block pavements inflict upon the public make their use undesirable.

As there are at present in this country many hundred miles of streets paved with blocks of stone, and as the use of these blocks seems likely to continue and to increase, a short account will be given of the sources of supply of these materials.

So far in this country paving blocks have been made in large quantity from granitic rocks only, in the main from granitites of the hornblendic varieties, and in part from the materials of that nature which have a uniform gneissic structure, though in New Jersey and elsewhere some success has been attained with basaltic traps. The conditions which have limited paving blocks, as regards the variety of stone, are substantially as follows: It is essential that the material should offer the utmost resistance to the crushing action of the wheel and of the horse's shoe, as well as the maximum resistance to the forces which tend to break it into fragments. In a word, it must be tough as well as hard. Still further, the stone must have three splitting planes, or rift lines, at right angles to one another, so that the blocks may be readily formed of regular cuboidal shape. So far as experiments have gone only the granitic and trappean rocks afford these conditions in a satisfactory manner.

As yet the paving blocks of this country have been produced mainly in New England and the neighboring States of the Northeast. Maine, New Hampshire, Massachusetts, Connecticut, and some other States

[1] It is commonly assumed that the Roman paved way was without other covering, and that the wheels and feet of the teams bore directly upon the stone block. From some personal study of these ways, as shown in their remains which have come down to us, I am inclined to believe that the stone was kept covered with a layer of earth deep enough to protect the unshod hoofs of the horses from the wearing which they would inevitably have encountered if they had trodden on the stone. Anyone who knows the condition of the bare foot of the horse, and who will examine the old Roman pavements, the blocks of which were sometimes of rough lava, is not likely to believe that these ways were used without a covering.

abound in deposits suitable for this use. Rocks of a similar nature occur in the Blue Ridge section of the Appalachians as far south as Georgia, though in the more southern portions of the region the process of decay has extended so deeply as in general much to reduce their value as sources of paving blocks. Still, such blocks of granitite of good quality are quarried near Atlanta, in southern Missouri, and in Wisconsin. In the Cordilleran district there are many granitic rocks which are likely in time to serve as sources of paving stone. It is probable that some of the granitic materials in the Ozark district of Arkansas may also serve this need.

It may be here noted that, so far, all the American experiments with paving blocks for carriageways have been made with small masses riven apart, and therefore with irregular surfaces. These roughnesses of fracture and the interspaces between the stones are what cause such pavements to be extremely noisy. Recent inventions have very much cheapened the cost of cutting stone by the method of sawing. The question therefore arises whether it may not be possible to pave with large rectangular blocks of granite, the edges to be fitted in the manner of closely jointed masonry, and the surface left smooth, or perhaps slightly roughened, to prevent the slipping of the horses' feet. Some difficulty may be encountered from the contarction and expansion in such a pavement with changes of temperature, but this might be met by the use of an elastic cement between the blocks. The endurance of a pavement of this kind would probably be much greater than that of one made of ordinary blocks, for the reason that the greater part of the wear which comes upon the faces of these riven stones arises from the up-and-down motion of the wheels over their rough surfaces.

PAVING BRICK.

Of late years the use of brick for paving wheelways has rapidly developed in this country. The system is ancient, having evidently been in use in Holland and elsewhere for a very long time. Although a tolerable pavement can be made of any clay suitable for the manufacture of ordinary building brick, provided the burning be effective, experience shows that to obtain the maximum hardness and toughness in such bricks it is necessary to make a careful selection of the materials, and an equally careful treatment of these materials as regards their admixture and the methods of burning. As yet none of the recently formed clays—those which have been made, and have remained since the making, on the surface of the earth—have been found as suitable for road-brick making as are those which are obtained from ancient deposits. There seems, indeed, to be some process, the nature of which is as yet unknown, that has taken place in ancient and deeply buried clays which has seemed to bring them into a condition where they bake into a peculiarly firm mass.

Clays which have been most successfully used for the manufacture of paving brick in this country are obtained from the Coal Measures of the Ohio Valley. In appearance these clays are not very different from some of recent origin, but they are rather more compact, and probably by leaching processes have been deprived of the free lime, potash, and soda which would serve to make them melt into glass under the high temperature to which they have to be subjected in order to bind the grains of the material effectively together.

In general, it may be said, so far as other than practical tests can indicate, that nearly all the formations from the Tertiary to the Cambrian abound in clays of a nature well suited to the making of a good paving brick. In many cases it will be necessary to subject the material to a grinding process, for many of these ancient clays are of too firm a texture to be broken up in a pug mill. Still, it may be expected that it will often be advantageous to incur this expenditure.

So far as I am aware, no experiments have been made in manufacturing paving brick from the extensive clay deposits known as the Devonian black shale, which extends from western New York throughout a large portion of the valleys of the Great Lakes and the Ohio, and probably to the westward, beyond the Mississippi. Many portions of this shale contain a large amount of petroleum and related substances, such as paraffine. Before the discovery of oil wells in this country, the material was extensively quarried and treated in retorts in the manner of coal in the production of illuminating gas, the volatile products being won by the distillation. In this way about 15 per cent in weight of shale was removed, the remainder forming a friable siliceous clay, which appears to be well adapted for making brick of the quality needed for street pavements. In some cases the shale can be made to burn in open heaps, though it is probable that if used for brickmaking it would be desirable to have the firing done in kilns, so arranged as to recover the paraffine and other distillates. If it were not desired to make other use of the products of the retorts they would serve in their original gassy form for burning the bricks, a process which is now to a certain extent accomplished by the use of crude petroleum.

In this connection it is interesting to note the fact that many of the best deposits of brick clay which occur in the Ohio Valley and the neighboring districts on the east owe their good quality to the fact that they are made up to a great extent of materials from the Devonian shales.

It is very much to be desired that careful comparative studies should be made to ascertain the relative value of the clays in this country for the diverse uses to which they may be applied. At present it seems impossible to accomplish a work of this magnitude without the assistance of the Federal Government. The importance of such a study of our clays which are suitable for making paving brick is the greater for the reason that a large part of the Mississippi Valley, as well as much of the area of the Gulf and Atlantic States, is destitute of material which, in its natural condition, can be used in roadmaking. Although it would be possible to import macadam rock from other fields, the cheapest resource will often be found in the excellent clays which abound in those parts of the country.

ACTION ON ROADS OF RAIN FROST, AND WIND.

It is impossible to understand the geological history of roads without some study of the effect which frost, rain, and wind have upon them. On account of the importance of their action, it will be necessary to consider these matters in a somewhat detailed way.

The effect of rain upon a highway is, first, to soften the bed, and next, to wash off the portion of the material which the temporary streams can bear along. On an ordinary dirt road the softening action is in high measure injurious, as it permits the feet of animals and the wheels of vehicles to penetrate below the surface. On a properly made stone road, such as devised by Macadam, as well as on all forms of block pavement, the road acts as a roof, shedding the water from its surface. If the way be skillfully planned the penetration of water from the sides is avoided, and thus the damage arising from the softening action, as well as from the influence of frost, is done away with. On all forms of dirt roads, and on the most of those made of gravel as well, the effect of the penetration of water in loosening the mass of the roadbed is serious, in most cases up to the margin of disaster. Here, indeed, we find the critical feature in all ill-constructed ways.

Where a hard road of macadam, or blocks, or other material impervious to water is properly shaped, the rainfall is quickly carried to the side ditches by the arched form of the way. On such roads the water never, even on steep grades, courses over the way for a much greater distance than its width. Thus arranged, the streams, even in a very heavy rainfall, do not gain much volume or attain great speed; therefore their scouring effect is but small. Nevertheless, the storm water, by removing the dust from the roads and by washing out the binding material between the stones, hastens the wearing of the way. This is especially the case where the macadam material is of the softer sort. Where the hardening is done with the firm basaltic trap rocks, the washing influence of the waters is not so serious. On dirt roads the rainfall, especially after times of frost, is the most serious agent of destruction.

When the frost enters the ground, the first effect is to convert into ice the water within the zone of its influence. In undergoing this change the fluid expands to the amount of about one-ninth of its bulk. The energy with which this expansion occurs is in all cases sufficient to thrust about the materials of the soil. So long as the road permits water to pass into it, and wherever ground water can penetrate from the sides beneath a way, however well compacted, even if it be quite waterproof, the action of frost is destructive.

There is a common opinion that frost works uniformly downward from the surface of the earth. A little observation on a freezing section of the soil will show this view to be erroneous. However uniform the texture and alike the materials of the detrital covering of the earth, the freezing process is extended irregularly downward. Although the whole of the earth for an inch or two in depth may become frozen at once, below that level the extension of the process goes on along particular lines, determined, it may be, by differences in the conductivity of the soil, but more commonly by the numerous and rather tortuous paths by which the surface water finds its way to the under earth. Thus it comes about that the expansive thrust arising from the formation of ice is carried laterally through the soil in such a manner as to shove the materials this way and that, but always advancing them in the direction opposite to that in which the freezing extends.

It seems likely that the growth of ice crystals, which is often so conspicuous a phenemenon on the surface of the earth on substances such as living or decaded wood, and which may be efficient in thrusting bits of stone to and fro, also goes on with the same effect in the earth. The writer has observed such crystals developing at a depth of an inch or two below the surface, and has seen reason to suspect their growth at a lower level.

The immediate effect of frost action on a well-paved road, where care has not been taken to keep the foundation dry, is to heave the pavement irregularly, the amount of the uplifting depending on the quantity of water which has become frozen. The effect of this irregular motion is to pull the cemented stones apart, and sometimes to form cracks through which the water can penetrate. Where the macadam is not well cemented, or where on a dirt or gravel road there are stones near the surface, the effect is often to push the larger bits upward to the surface. It may in general be said that all frost action is highly detrimental to a road, and that therefore the utmost care to exclude the water from the hardened part of the way, as well as from the under earth, needs to be taken.

It is likely that the process by which soils and other detrital materials on the steep slopes work downward is in good part accounted for by the thrusts which arise through the repeated freezings and thawings to which the soils of many countries are subjected. In a single winter it may happen that freezing to the depth of a foot or more, followed by thawing, repeatedly occurs, and each movement may result in pushing a fragment of stone for the distance of as much as an inch. As the motion will take place more readily down hill than up, the tendency is to move the detritus in the direction of the slope. Moreover, in all cases, frozen soil rises a little above the level it had before the frost penetrated it. When the frozen condition passes, the fragments return to a lower level, and in doing so are free to move down the slope. In this manner we may account for the fact that in countries much subject to frost mountain slopes of a given declivity are prevailingly less occupied by soils than is the case in warmer climes. A result of this action is sometimes noticeable in the gradual movement of a roadbed down a slope on which it lies.

The action of wind on roads of all descriptions is considerable. The effect is to remove all the loose material of a fine-grained nature as soon as it becomes dry. On dirt roads and those of gravel the wearing action thus accomplished, though it takes place in a more even way, and therefore is less conspicuous, is often as great as that brought about by the rain. On the macadam roads the effect is considerable, but on the whole not seriously damaging, except where the pavement is made of rocks which easily powder. On the limestone roads of the Mississippi Valley, where the rock which is used powders rapidly, the dust is quickly swept from the roadway to the adjacent fields. At many points in Kentucky the writer has observed that a wide strip on the eastern side of the limestone roads has become noticeably enriched by the fertilizing dust borne to it by the prevailing westerly winds of the summer season.

EFFECT OF GEOLOGICAL STRUCTURE ON GRADES OF ROADS.

Almost as important as the character of the surface of a road is its grade—a feature which is determined by the contours of the country over which it is extended. Experience has shown that, except under peculiar conditions, it is very unprofitable to build roads having slopes exceeding what is commonly termed 5 per cent, i. e., 5 feet of fall in each 100 feet of length. A country which admits of roads being made over it with no greater slopes than 5 per cent may be said to be naturally well conditioned for roadbuilding. Where the grades necessarily exceed that angle of slope, the region may be termed disadvantageous for roadmaking.

It should not be supposed that a perfectly level country, or those regions which most nearly approach a horizontal surface, affords the best conditions for road construction. Such level fields are disadvantageous in two ways: In the first place, the unvaried resistance of the load to the traction of the animals is an evil, for it imposes on the creatures hard labor with no intervals of comparative repose, such as they have when the vehicle moves down slopes. Although there are no data to determine the matter, it seems likely that for the work of draft animals a way having successive slopes of about 6 inches in 100 feet, each slope occupying the length of about a mile, would be best suited to the needs. Something like the same inclination is demanded in order to secure an adequate drainage to the ditches on either side of the roadway. With a less slope than from 6 inches to a foot in 100 feet—the measure depending on the nature of the soil and of the rainfall—the roadbed can not be retained in a sufficiently dry state.

In a mountainous district, especially where the elevations have not endured long enough for the rivers to carve deep and broad valleys, the conditions under which the roads are laid out are generally such as to impose a very serious burden, which we may call the grade tax on the transportation of the country. In certain sections of the United States, particularly in the Alleghanies, where there are many long, parallel ridges with few gaps breaking their rampart-like outline, the difficulty in the way of good roadmaking which the topography imposes is very great. The only methods of meeting this evil are as follows: Where the roads are properly planned, in relation to waterways or railways, it is generally possible to arrange the transportation so that it will not encounter the main divides. Generally, however, the roads are planned originally with reference to neighborhood convenience, and these local ways are afterwards made parts of through routes. The result is that when the country becomes thickly settled a system of highways exists which is a very serious tax on the earning power of the Commonwealth. The writer has estimated that in certain of the Appalachian States the unnecessary grade tax arising from the injudicious placement of highways amounts to as much as one-fourth of the total cost of wagon transportation over such roads. This evil can be met only by placing the main ways of each State under the control of authorities properly skilled in making roads.

Another evil arising from steep grades is found in the excessive action of the rain water which courses over them. As before remarked, the skillful road engineer provides for the speedy discharge of the water into the gutters by arching the pavement. It is, however, not practicable to give this slope from the center a greater fall than about an inch to the foot. The result is that the steeper the grade the longer the distance the water will flow over the pavement before it is discharged into the gutters. Moreover, these side channels, where steeply sloping toward the base of the declivity, have to be carefully paved, at an expense which may be as great as that incurred in building the traveled part of the road. It may also be noted that where the inclination of the way exceeds 1 foot in 20, there is, on certain soils of a prevailingly moist nature, a tendency of the pavement slowly to creep down toward the base of the hill.

In avoiding the difficulties incident to a rugged topography, the skill of the trained highway engineer is even more called for than in the construction of the roadbed. The latter task may be a matter of prescription, and can be done in a routine manner. The former demands a large element of judgment, which may be aided by a knowledge of the geological structure of the country. In order to avoid steep grades, the necessary recourse is to an elongation of the way by a system of zigzags. In laying out such a road it is necessary to take into account the character of the bed over which it passes, in order to avoid bad foundations or materials which are in motion in the manner of the slow landslides which often creep down slopes of high angle.

It is well to remark that in almost all steep slopes which are covered with loose material the débris, if it be not in the state of slow movement, has attained a state of repose which is so delicately adjusted to its conditions of weight and declivity that a scarf for a roadbed cut on the inclined surface will again set the mass in motion, either in the form of landslides or a slower movement, which in the end entails a long-continued and serious expense in the way of repairs. Such movements are particularly common in loose materials in countries where the frost penetrates deeply and the ground becomes very soft in the time of thawing. In this country the mischances arising from ignorance on the part of those who have undertaken to diminish grades by the zigzag method have been very numerous, and in some sections, particularly in New England, the people have, by reason of such experience, become disposed to accept grades of 10 or 12 per cent rather than to enter on the perplexities which the elongation of the road might entail.

In many mountain districts, as the Swiss experience has shown, it is often better to carve an important road in the face of a precipice, even if it must be an almost continuous tunnel, than to incur the grade cost of directly crossing the elevation. In some cases, as in that of the tunnel which carries the main road from the city of Naples eastward, the construction is ancient. There are other European examples, dating from the Middle Ages or earlier, where important highways have been horizontally extended for a great distance through deep ridges. In the main, however, such costly highways are the work of this century. Although the first cost of such construction is large, the permanent economy often justifies the expense.

Even when a country is not mountainous, various features of its structure may produce a decidedly irregular surface where, though the relief may not be strong, the difficulties of adjusting roads in such a manner as to avoid a heavy grade tax is considerable. The commonest class of such surfaces is where, though the area may in general be that of a table-land, the streams have cut deep valleys, as is the case, for instance, in the limestone district of central Kentucky. In such a region the aim should be to place the main ways, where possible, next the streams, so that the outgoing produce of the fields may have the advantage of continuous down grade to rail or water ways. It often happens, however, that in such a region the rivers are in canyon-like gorges, where roadbuilding would be very costly. In general, in such indented tablelands the fit place for the main ways is along the divides, or watersheds, between the streams. Where such country is intersected by railroads it is usually best to organize its trunk wagon roads in the manner indicated.

The most perplexing surface over which a roadmaster is called on to construct main roads is that which has been shaped through the accumulation of glacial drift deposits on a preexisting river topography. In an area of this nature the elevations and depressions, which elsewhere are usually organized in a system which can readily be remembered, are disposed in a haphazard manner, so that nothing but a well-made contour map or a very careful and extended system of surveys along different lines will enable the surveyor to lay out his way in a judicious manner. In the Commonwealth of Massachusetts, where the total length of public roads in an area of 8,500 square miles amounts, exclusive of city streets, to about 22,000 miles, it is difficult to find a stretch of road 10 miles in length which does not exhibit a number of blunders in construction due to an inadequate foreknowledge of the surface on the part of those who laid out the way. A close study of certain selected areas has led the writer to the conviction that in this State the average excess of grade over that which might have been had if the roads had been skillfully laid out amounts to about one-third of the total of all the declivities. The measure of the loss thus entailed may be better understood from the following estimate: The average grade of the Massachusetts roads is probably at least 2 per cent, which, for the length above given, makes the total height climbed by a vehicle which should traverse the whole of the length about 440 miles. Thus the saving in the aggregate ascension accomplished by the vehicles of the Commonwealth in the course of a year's work amounts to about 145 miles multiplied by the average number of trips made over the surface. As yet such computations lack statistical value, but they indicate an enormous expenditure of energy in the wear and tear of vehicles and of teams, in the time wasted by slow going, and in the successive journeys which the steep ways and small burdens entail. To plan roads discreetly in a drift-covered country, such as New England, demands good maps. To do the work well it is necessary that these delineations of the surface should be of a high order of accuracy. It is easy to show, however, that were the highways organized in the manner in which they could be by the use of such maps, the saving in the matter of roads would in time—indeed quickly—far more than repay the cost of the surveys. Herein we find what is perhaps the strongest of the many arguments for the prosecution of the topographic work of the U. S. Geological Survey.

In the greater part of this country the roads are already so far organized that any considerable change in their position will entail a great amount of expense. Experience shows, however, that where a region is well mapped and the highways are under the management of competent engineers, it is usually possible, from the system of ways, to select and maintain a set of main roads to which the others may serve as tributaries. It is also possible, by study of the traction charge as dependent upon slopes and the character of road surface, to establish a plan of improvement which will gradually reduce the cost of carriage by wagons.[1]

[1] In the present condition of road construction in this country it appears very desirable to have some simple method of testing the traction resistance of roads. It seems to the writer that the production of such contrivance is worth the attention of American inventors. It should not be a difficult matter to arrange a recording dynamometer in connection with an ordinary freight wagon which would give an index of the resistance on each section of the road under observation. A part of the evils of the road tax from which our people now suffer, especially their patience under the inflictions, arises from ignorance as to the precise amount of loss which the present ill condition of the roads entails.

Within the areas where the form of the surface is due to the action of glaciation, as well as in some of the Southern States, the occurrence of extensive peat bogs makes the construction of roads of desirable directness a matter of much difficulty. Except where the conditions are such as to permit costly fillings, experience shows that it is generally cheaper to bridge these obstructions than to build causeways over them. In all cases it may be safely reckoned that peaty matter will not support an embankment; although for the moment it may bear up the load, it will slowly slip away from beneath it until the weight finds its way to the bottom. The conditions, indeed, are substantially those in which a filling is made in water, except that the subsidence which takes place in peat may require years for its accomplishment. The only advantage in constructing upon peat rather than in water is that in the bog the side slopes of the embankment retain an angle of declivity generally lying between 45° and 55°, though it varies somewhat with the character of the peat.

In certain parts of this country, particularly along the shores from Massachusetts to the Rio Grande, the roadmaster has to contend with drifting sands, which, after the manner of snow, tend throughout the year to replace the constructed way with shifting materials which resist the movement of a vehicle in a very effective manner. The only known remedy for wind-blown sands is found in fixing the surfaces of the dunes by means of those species of plants which will grow under the difficult conditions which such fields impose. In Europe it has been found possible by the use of native and naturalized plants to cover the surfaces of wind-blown sands so effectually as to stop their progress.

In many regions where the sands were fixed by vegetation until the surface was broken by wheel, the earth material, when it becomes bared of its vegetation, is almost as mobile as the dune sands. Wherever possible, the trackway of such a road should be excavated and the place filled with suitable materials. Unfortunately, however, this method is inapplicable to many regions, so that temporizing expedients have to be sought. Some of these may advantageously be noted here.

Along a large part of our shore from Cape Ann southward to the Rio Grande the marine marshes behind the beaches contain very extensive beds of oyster shells. These materials are frequently accessible at low tide, and in almost all the lagoons they are readily obtained by simple dredging. Even where oysters no longer live, as in the region about Boston Harbor, the deposits nearly at the level of low water which are composed of these shells are very extensive, there being hundreds of acres of such accumulations lying a little below the muddy coating which covers the flats of Massachusetts Bay. Along the coast-line of the Middle States and in the contiguous country of the Southern States where higher-grade road materials are not accessible, these fossil oysters may advantageously be used. In the opinion of the writer, there are few stretches of 25 miles along this coast south of Portland, Me., where accumulations of this nature may not be found. It is worth while to note the fact that these deposits are rarely to be seen on the surface; they are commonly buried beneath a layer of mud or sand.

Most sandy roads may be much improved temporarily by covering them with a layer of clay. For this purpose plastic clay, that which when wet may be molded, as on the potter's wheel, is to be preferred. Mixed with the sand, it soon becomes hard; the clay serves as a binding material, and thus greatly diminishes the shearing motion of the road stuff under the pressure of the wheel. If nothing better can be obtained, the clay from marine mud flats should be used on the sandy seaboard ways, where the travel is sufficient to justify their improvement.

On ordinary sandy roads, where no other recourse is possible, it is advantageous to have two roadways adjacent to each other, one of which can be allowed to become covered with natural or planted grasses while the other is in use. The effect of the growth of vegetation is to promote a certain binding action. The influence of the fallow state is in many cases evident for a year or two after the way is again occupied by the wheels. In most cases, however, on exceedingly sandy roads it is best to favor the movement of vehicles in such a manner that the wheels will run in permanent ruts, with a strip of vegetation on either side. The passage of carriages can be arranged for by turn-outs. Where the traffic on the roads is considerable accommodation can be made by establishing two such trackways, each for vehicles going in one direction. In some parts of southeastern Massachusetts, especially on the island of Marthas Vineyard, these single-track ways have been long in use, particularly in the glacial sand plains. They are not found to be seriously inconvenient even where the number of vehicles amounts to as many as 50 a day. Turn-outs are arranged at intervals of about 100 yards, and are placed so that they may be intervisible.

In single-track roads the wheels, always moving in ruts, press the earth over which they move into a firm mass. The ruts become filled with dead leaves, which assist in binding the detritus. Experience shows that roads of this nature on level surfaces of sand can be kept in excellent order, as certain of them are in Dukes County, Mass., at an annual cost of less than $3 per mile, and this where the traffic is of a rather heavy kind. The only repairs which are required consist of filling in the ruts when they have become worn too deep for the wheels.

SOURCES OF SUPPLY OF ROAD STONE.

The most important question now before our roadmasters is that which concerns the sources whence the rock material to be used in highway construction may be drawn. On this account it seems well to give a statement of those facts which are at present known concerning the distribution of such rocks. It should be noted that although the geology of this country has been extensively studied, and is in general well ascertained, scarcely any attention has been paid to the value of the different stones in roadmaking, or to their distribution. The writer has to rely, therefore, upon a limited experience which he has personally gathered during recent years, and on information which he has been able to obtain from other officers of the U. S. Geological Survey, and from the publications of the State surveys.

From the point of view of its road materials the United States may be conveniently divided into five areas, which, be it said, are only in a general way distinguished from one another. These are as follows: New England; the Appalachian belt, from the St. Lawrence southward, including all the southern elements of that mountain system; the Coastal Plain, extending from New Jersey to Texas; the Mississippi Valley, including the plains country westward to the Rocky Mountains; and the Cordilleras, including the western third of the country. These several districts will now be considered in succession, with the intention of pointing out the most available roadbuilding materials, so far as they are known in each.

NEW ENGLAND DISTRICT.

The district of New England is in general remarkably well supplied with the rocks which are fitted for roadbuilding. It is, indeed, doubtful whether any other portion of this country so abounds in stones suited to this use. On the western border of this area, in the Berkshire Hills and the Green Mountains, there is, it is true, a field where the stone is generally of a schistose character, and of a nature which is not usually suited to roadmaking. Moreover, in this district, though dikestones occur, they are relatively infrequent, and the fissures which they fill are usually rather narrow. Fortunately, however, in the valley of the Connecticut River, from near its mouth to the northern border of Massachusetts, there is a great array of trap rocks and of lavas which were poured out on the sea floors of the Triassic age—rocks which are not only of excellent quality for roadmaking, but which occur in deposits forming high cliffs and are therefore very well placed for quarrying. These Triassic traps and lavas are the most valuable roadmaking materials in the district which we are now considering. From them the region westward of the Connecticut, as far as the Hudson Valley, can be conveniently supplied.

East of the Connecticut, and thence to the coast-line, trap dikes are of frequent occurrence and granitic rock is abundantly found, but the deposits of trap are generally costly to work, for the reason that they lie in narrow crevices, and the granitic rocks afford road materials of only the second class. Fortunately, the greater part of this area lies within 100 miles of the great trap deposits of the Connecticut Valley, and can therefore be supplied from that source. As we approach the coast-line of New England the trap dikes become more numerous than in the interior districts, and though none of them are as large as those in the valley, we not infrequently find deposits of 100 feet or more in width. Some of these are readily workable. One such in Waltham and another in Salem, Mass., are now the seats of a considerable broken-stone industry. In Rhode Island the dikes are few and mostly of small size, and none have yet been found which are likely to be worked for road materials, except it may be the deposit of magnetic iron ore in the town of Cumberland known as Iron Hill. The same is the case with the sea border of Massachusetts, except for a single dike in Salem, above referred to, and another in the town of Quincy known as Houghs Neck, where a dike having a width of about 100 feet may perhaps afford the conditions of profitable working.

On the coast of Maine there are very many large dikes, as well as some ancient lava-flows. These deposits are most numerous along the coast from the mouth of the Penobscot to Passamaquoddy Bay. None of them have been carefully examined to determine their value for use on roads, but it seems probable to the writer that owing to their generally good character and their convenient position in relation to harbors they are likely to be made the basis of a considerable export of road stone to points along the Atlantic coast.

In the interior district of Maine, owing to the great thickness of the drift deposits and the generally poor quality of the bowlders, road stuff of a suitable grade is hard to find. It may, however, be obtained at small cost from the rocks of the coast belt.

Eastward of Maine, along the shores of the Bay of Fundy, trap dikes having in general the character of those of the Connecticut Valley again occur. Although this district is outside the United States, and therefore beyond the field to be considered in this report, it may be said that the Bay of Fundy offers an interesting field for exploration on the part of those who may wish to obtain cheaply traps accessible for water transportation to the New England coast.

It may be remarked that only one field of New England has been found unsupplied with stone which could be made tolerably serviceable for roadmaking. The island of Nantucket, being made up of sands and clays of glacial age, has so few pebbles or bowlders in the mass that it will be necessary to import stone for its roads.

The drift materials of New England are, except in the Berkshire Hills, the Green Mountains, and the central and northern parts of Maine, generally well suited for road purposes. In fact, if it were not for the ample supply of excellent bed-rock stone they would have distinguished value. As it is, they may be reckoned as a valuable resource in the southeastern portion of the area, where, as in Barnstable and Dukes counties, Mass., good road stone is not otherwise accessible.

APPALACHIAN DISTRICT.

In the Appalachian section south and west of the Hudson the most satisfactory source of road materials is to be found in the traps of Triassic age, the equivalents of those in the Connecticut Valley, which are found on the eastward side of the Blue Ridge or its northern equivalents, from near New York to South Carolina. At the northernmost point of their appearance in this district, in the Palisades of the Hudson, these traps are admirably placed for convenience of transportation. They are of excellent quality and of great thickness. They can be taken by ship to the open sea, by boat through the Erie canal, or by railway to any point.

Southward in New Jersey the Triassic traps are abundant, and so placed that they may be very conveniently worked. In this field, as in the Hudson, traps of this age generally exhibit the columnar structure so common in the basalts, a feature which makes the rocks easily broken from the quarry.

In the New Jersey highlands hornblendic trappean rocks occur in large quantities about the iron mines. The waste heaps afford quantities of these materials, conveniently placed for use. Although not of the best quality, this stone may be reckoned as fairly well suited for macadam roads.

The rocks known as gabbros, which occur in western Delaware and about Baltimore, appear to be promising sources of supply for such materials. They are evidently of a very firm nature.

From New Jersey southward the Triassic traps occur in small masses. They have not been explored, and it is doubtful whether they are so placed as to have much value for roadmaking. In this more southern section resort must be had to the trap rocks of the Blue Ridge or its southern equivalent, the central ranges of the Smoky Mountains. Here, again, little is known as to the distribution of these rocks, but it seems likely that exploration will develop them in suitable quantity and quality as far south as northern Alabama. In this region, as elsewhere, there is great need of extending our knowledge of road-building material.

In the Smoky Mountain district there is a number of localities where extensive veins of magnetic iron ores occur, though owing to the admixture of various impurities the material is not fit for making iron. It seems not unlikely that these ore deposits may serve in the construction of roads. Some observation which the writer has made leads him to suppose that fragments of this rock will cement well and prove strong against the tread of the wheels. There are also numerous crystalline rocks in this field, more or less resembling granite in structure, which will afford good road stuff, though it is less valuable than the materials above mentioned.

At various points in the Appalachian district, particularly in the Cumberland sections, quartzites abound—beds which, though originally sandstone, have, in the processes of mountain building to which the rocks have been subjected, been converted into a flinty material, which is tolerably good for use in roadmaking, though it does not cement very well and is not very resistant to wheels.

In the Alleghany and Cumberland districts the shales, particularly those commonly known as the Devonian, or Ohio, shales,[1] constitute an excellent material for roads where the traffic is not heavy. It is a peculiarity of this material that it breaks into thin, shingly layers, which are moderately tough, and although they do not bind well together, they servė by their form to uphold the wheels. Those who have traveled much in this part of the country must have observed how very good the roads are where they pass over beds of this shale. These ways can be maintained in excellent condition with very little work. They often remain smooth and hard though left quite without care for a score of years. Although the materials from the Devonian beds are not sufficiently valuable to make it worth while to transport them for considerable distances, they are worth attention for use in the neighborhoods where they occur.

We may also note the value of the numerous bedded iron ores which are found at many points in this district, particularly in the fields to the west of the old central mountain axis. These deposits, when too lean to be worked in the furnace, often afford very good road materials. They are particularly adapted for use as a cement with which to bind together the fragments of other kinds of stone. The iron oxide thus proves in many cases a valuable resource.

The low-grade iron ores which we are now considering are so widely scattered throughout the Mississippi Valley that it is difficult in a report of this nature to give any indications as to their locations which will be of value to the roadmaster. In general it may be said that wherever a limestone occurs beneath a considerable thickness of shales and sandstones the upper part of the limy layer will be found to be replaced by iron oxide. The upper limestone beds of the Clinton, the Oriskany, and the sub-Carboniferous are commonly thus transformed, while here and there in the Coal Measures thin layers of such ores exist. The existence of these beds is frequently revealed by pits dug in the earlier days of this century, when iron was high priced and the early settlers were ever seeking an opportunity to engage in its manufacture.

In and about the southern Appalachians there are many deposits of conglomerate, some of which are likely to prove of considerable value to the roadmaker. The oldest of these beds, that known in eastern Tennessee and western North Carolina as the Ocoee formation, would be of value as a source of road stone but for the fact that it lies in a district which is well provided with more serviceable materials. The conglomerates of the sub-Carboniferous age, occurring as they sometimes do in regions destitute of other hard rocks, may occasionally prove of value, particularly in Pennsylvania.

[1]As there are several Devonian shales, I have, in the reports of the Kentucky survey, second series, endeavored to affix the name Ohio shales to this deposit.

COASTAL DISTRICT.

For present purposes the coastal belt of eastern United States may be taken to include all the lowland districts lying between the Hudson and the Rio Grande which are underlain by deposits recently formed on the sea floor. So far as these deposits extend, the country is imperfectly provided with rocks suitable for use in roadbuilding. If we except the Lafayette formation (see p. 277), the newly made beds themselves are usually of an incoherent nature. There are, so far as known, no dikes within this district, and the recent strata hide all the lower-lying and more firmly organized beds. Therefore the better kinds of roadmaking materials used in this district will have to be imported from beyond its limits.

Fortunately for the needs of the coastal belt, roadbuilding stones of good quality are generally accessible in the country lying to the north of that area, and this without excessive cost of transportation. The greater part of the area is within 200 miles of the old axis of the Blue Ridge, where tolerably good road stones abound. The remainder, the region near the Mississippi, is poorly provided; it seems likely, indeed, that materials from which macadam can be made will have to be imported into that section by sea from the North Atlantic coast, or perhaps by water transportation from the Ozark Mountains and other regions in Arkansas and Missouri, where a number of rock species well suited for road work occur in positions near the navigable rivers.

Along the costal belt of the Atlantic and for a considerable distance westward in the Gulf States the wide distribution of the Lafayette formation affords the country fair opportunities for good roads at the minimum expenditure. Here and there this deposit contains an excessive amount of clay, and is, therefore, particularly in the winter season, likely not to uphold the wheels. In general, however, if the roadbed is kept dry by means of deep side ditches, the way can readily be maintained in what may be described as that of a first-rate second-class road. This remarkable deposit extends in its characteristic aspect from northern Maryland to central Florida. Mr. George H. Eldridge informs me that near Bartow Junction, in the latter State, the deposit takes on an even better character, forming a compact road, the material being indeed of such value that it is shipped to the chief towns, where it is used in making streets.

At Gainesville, Fla., beds probably of the same age, but containing more or less lime, both carbonate and phosphate, and also some iron, are used for roadmaking and shipped to various places in the central part of the State.

Along the banks of the greater rivers which have their headwaters in the Appalachian uplands there occasionally occur gravel deposits the pebbles of which, being of crystalline rock, are fit, after crushing, to be used in making roads. The quantity and quality of these gravels are not well known. They seem likely, however, to have an importance, for the reason that they occur in a district singularly barren of hard rocks. Of these the Paducah gravel is the most characteristic deposit (see p. 273).

In the central part of western Florida deposits containing abundant pebbles of lime phosphate abound. Similar beds exhibiting the same materials in less quantity occur at points in southern Alabama and Mississippi. Where these pebble phosphates are of the first quality they are of such commercial value that they can not well be looked to as a source of road material. Experience shows, however, that the deposits of pebbles at certain points have peculiarities, such as an excess of lime carbonate, which make them of little value as a source of fertilizing material. In such cases the pebbles may well be used, after breaking, for road purposes. Pebbles of lime phosphate are harder than ordinary limestone, and the fragments cement well together, so that the material forms a good road metal, one which may be of great value in a region where roadmaking stones are of rare occurrence and the need of hardened ways is very great.

It seems not unlikely that some of the districts about the ports on the Gulf of Mexico may well look to the crystalline rocks of the West Indies as sources of road material. A large trade in coal and breadstuffs is now growing up between our Gulf ports and those about the Caribbean, and return freights, or at least ballast, of roadmaking stones might well be brought to this country.

In many parts of the coastal belt, especially in and near the great cities, it will doubtless be found advantageous to use brick pavement for the wheelways. On this account it is important to note the fact that the clays suited to making high-grade brick occur plentifully in various sections, while fuel, either coal or wood, is generally not remote. In some sections it will probably be found to be cheaper in the end to pave with bricks made from these local clays than with macadam stone brought from a great distance, for although the first cost of such pavement is high, the expense of its use for a term of twenty years is relatively not so.

In certain sections of the coastal belt, particularly in those regions next the shore, some use is made of marine shells, which frequently make up all the mass of extended beaches. Roads thus constructed are of excellent quality, but their endurance under traffic is so poor that except where the carriage of the shells is but for a short distance they can not be regarded as economical.

At some points on the coast of Florida and elsewhere the beach shells have become cemented into a compact limestone which is fairly serviceable for building purposes and is locally essayed as a roadmaking material. In view, however, of the ease with which the stone grinds into dust, it is not to be commended, save where no better material is available.

The State of Texas, owing to its great area and the prevailing bad character of its roads, requires a somewhat special treatment from the point of view of the materials within it which are fit for use on highways. An excellent sketch for such a study has been made by Prof. Robert T. Hill,[1] of the U. S. Geological Survey. The following statements concerning this district are condensed from Professor Hill's memoir:

At Pilot Knob, 7 miles southeast of Austin, there is a large mass of basalt which is admirably adapted for roadmaking. This substance can advantageously be used, at least for a top coating, on the roads lying within 50 miles of the locality. Other localities of basalt are known in the country south of Austin, but details concerning the quality and accessibility of the materials are lacking.

Next in value to the basalt as road material are the gravels which are considerably developed in different parts of the State. These vary a good deal in origin and character, but are all worthy of attention.

The plateau gravels, deposits which are not distinctly related to the streams, are thus described by Professor Hill:

> Along the eastern side of the Black Prairie region are immense deposits of gravel, the pebbles being of various sizes and composition. In the northern portion of the State the gravel is mostly composed of quartz and chert derived from the ancient mountain region of Arkansas and the Indian Territory. East of Austin and to the northward it is mostly composed of flints derived from the Grand Prairie region. These are often as large as a human head and would serve well for a Telford foundation, but as often now used they are an injury to the roads. In many places, however, this gravel is of sufficient size for top dressing and occurs in inexhaustible quantities.

Along the principal streams in and near the Black Prairie region, as in the case of the Brazos, the Red, and the Colorado rivers, there are extensive deposits of gravel well suited for roadmaking. In Travis County the terrace deposits of the Colorado contain gravel for a distance of from 1 to 3 miles on each side of the river. Where these deposits come to the surface the roads are excellent. Where they are wanting the ways are almost impassable.

Akin in origin to the pebbly gravels are the deposits of flints which abundantly occur on the flat-topped divides of the Grand Prairie to the west of Austin. They are residual materials left from the disintegration and removal of the chalk and chalky limestones.

Professor Hill notes the occurrence of several chalky limestones, of which that known as the Shoal Creek limestone seems to be the best suited for roadmaking purposes. Lower down in the series of the chalky limestones is that known as the Washita. Although Professor Hill considers these limestones as fit for roadmaking, the hand specimens which I have seen indicate that the material is rather too soft for such use.

[1] Roads and Material for their Construction; Bulletin of the University of Texas, December, 1889.

Beneath the Washita limestone there lies a deposit of much harder lime rock, having in general the character of the Cretaceous and Jurassic limestones of France and Switzerland, materials which have been found to be fairly well adapted for roadmaking.

The yellow marls, Fuller's earth, and oolites which occur in the Grand Prairie district appear from the descriptions of Professor Hill to afford satisfactory materials for local use.

MISSISSIPPI VALLEY AND GREAT LAKES DISTRICT.

The most difficult problems connected with road construction in this country are presented by the central or plains section of the Mississippi Valley. Throughout this great expanse of nearly a million square miles the underlying bed-rocks are horizontal and generally too soft for road purposes; they are, moreover, essentially without dikes or volcanic deposits.

In considering the importance of the roadway problem in the Mississippi Valley, the fact should be noticed that the region is well adapted to tillage, with the exception of a small portion of the territory west of the Mississippi where the rainfall is insufficient. As a whole, it is the most fertile area of equal size in the world. The most serious qualification to its agricultural value is that which arises from the badness of its highways and the difficulties that have to be encountered in finding suitable materials with which to build them.

It may be assumed that the underlying rocks of this field are essentially unfit for making roads, though they may, perhaps, in default of better, be used for that purpose. The least objectionable of the native stones are the hard limestones of Silurian and Devonian age. These rocks are easily quarried and broken; they compact well under the roller, or even by the tread of wheels, but the rate of wear per unit of traffic is so great that they can be maintained only at a large annual cost. The amount of damage done to the road to a given amount of travel is probably five times as great as upon a road formed of the better trap stones.

Poor as the limestones of the Mississippi Valley are for roadmaking, nearly all the macadam roads which have been built in that section are made of such rock. One effect of its use has been the establishment and long continuance of the toll-road system, a system which confesses that the roads are too costly to be cared for at the expense of the community which they serve and are therefore turned over to stock companies. It seems to the writer that the perpetuation of the toll-road system in prosperous communities, such as those found in the limestone districts of Kentucky, can be accounted for in part, at least, by the great cost of maintenance of such ways which the use of limestone in their construction entails.

Next after the limestones, in generality of distribution, we may reckon among the possible roadbuilding materials the drift deposits of the

Mississippi Valley district. These are plentiful, and afford the most valuable pebbles for roadmaking in the States of Ohio and Indiana, but they deserve consideration in northern Illinois, Michigan, and the States farther to the north and west. No studies having been made of these deposits from the point of view of their use for road material, only the most general information concerning their occurrence can be given here. It may be said, however, that the value of these beds rarely appears on superficial inspection. It often happens that although the surface may appear unprofitable from its sandy or clayey nature, pebbly or bowldery beds exist at a slight depth. To elucidate these features of the distribution of these materials will require a careful inquiry. When found, these deposits of rock fragments will have to be separated from the finer detritus, either by screening or by washing, and the bits thus obtained will have to be passed through crushing machines in order to obtain the fresh fractures which are required for macadam roads. In general, it may be said that about one-third of the Mississippi Valley district is likely to obtain tolerably good road-building from these deposits of pebbles imported into it by glacial action.

The pebbly waste from the glacial deposits has in many cases been so concentrated by stream action that the fragments have been accumulated in the river beds and alluvial plains apart from the finer material. As these deposits come to be sought for they will doubtless be found valuable sources of supply (see p. 274).

Turning now to the sources of road materials which exist on the periphery of the Mississippi Valley district, we note the following facts: On the north of this field, in Canada and northeastern Minnesota, as well as in the upper peninsula of Michigan, there exists a great array of dike-stones and other hard crystalline rocks which are well suited for road-making. Although these materials are rather remote from the region south of the Great Lakes, it seems likely that they may be of some value as sources of supply.

On the east of the great valley the highway road materials of the Atlantic Coast belt may be reckoned as too far away to be of use. In the Smoky Mountain district of western North Carolina there are, as before noted, rocks suitable for roadmaking which, without undue cost, can be made to serve the needs of a considerable section of the southern part of the Ohio Valley. The Ozark Mountain area and the neighboring parts of Missouri, though their geology is as yet imperfectly known, seem likely to afford good road materials from their novaculites, or whetstone rock, as well as from their dikes and other crystalline materials. This source of supply should be available for the States of Missouri and Arkansas and parts of neighboring States. On the western border of the area the traps and lavas of the Rocky Mountains may be reckoned on for the supply of road stuff for a considerable area near the eastern margin of the Cordilleras.

It appears evident to the writer that in a large part of the Mississippi Valley it will in the end be found most convenient and most economical to construct the foundations of a macadam road of the cheaper and easily obtained limestones or other sedimentary rocks, covering the surface to the depth of not more than 3 inches with imported traps of the best quality. In this way the strength of the road is obtained by the use of cheap material, while of the dear only enough is used to insure a hard bearing for the wheels of the carriages and the feet of the draft animals. In those parts of the valley where the distance from trappean rock or glacial pebbles is so great as to make macadam roads undesirable, recourse will necessarily be had to brick-paved ways. In general, these will be so constructed as to afford the narrowest possible trackway for winter use, with a broader ordinary dirt road for summer travel.

The probability that brick pavement will be extended from the cities to the country roads makes it desirable to have a careful study instituted as to the relative value of the clays of this region which are fit for making bricks of the quality required for such pavements. As yet the value of these clays has been proved but in few localities. There is reason, however, to believe that they are of widespread occurrence, and the coals which are to be used in burning the clay are also present or near at hand in the greater part of the area.

So little has been done toward investigating the materials suited for roadbuilding in the central portions of the Mississippi Valley and Great Lakes district that not much can be stated in this report which will be of value to those engaged in constructing highways. In the following pages, however, some indications will be given which may prove useful.

East of the hundredth meridian and north of the Ozark field the valley of the Mississippi contains, so far as known, very little in the way of trappean or other igneous rocks. There are reasons, however, to believe that a detailed inquiry may here and there reveal deposits which, though not conspicuous on the surface, may, when properly opened, prove to be of value. Thus in Kentucky, quite by chance, two dikes of a traplike nature, known as peridotite, have been discovered in recent years. These masses, unlike most of similar nature, are not marked in the topography, and were noticed only by reason of their decayed portions, which made a peculiar stain upon the surface that led inquiring land owners to dig into them. So far the inquiry into their constitution has been limited. The openings have not penetrated below the zone of superficial decay, so that it is not known to what extent they may afford road materials, though it may be said that the indications are promising for such a supply. It is eminently probable that there are many such deposits, though in all cases it is to be feared that the material will have value only on account of the decay to which it has been subjected at a considerable depth beneath the surface.

The most widespread of the firm rocks in the Mississippi Valley are the limestones, those which range in age from Cambrian to Carboniferous. As may be seen by consulting any geological map of this part of the country, the limestones of this valley have a wide range. At almost all points east of the Mississippi River and north of the Gulf States, and in the tier of States immediately to the west thereof, there are few points where accessible deposits of these limestones are more than 50 miles away. It is true that the roads made from them will, as before noted, lack endurance, and are therefore sure to be very costly, on account of the expenses of repair. They are destined to be much used, however, at least in the first stage of road improvement of that district.

The lower-lying limestones of the Mississippi district, those of Cambrian and Silurian age, have been extensively essayed in road construction in the central and southern portions of the Ohio Valley. As a whole, these stones, though in appearance tolerably firm, have been found too friable to afford good road materials. The Upper Silurian limestones, particularly in the region within 100 miles of Cincinnati, are generally of a firmer texture than those of lower horizons, though the material is occasionally rather sandy. By proper selection of the beds from which the supply is obtained it seems likely that good road material may be secured from these deposits.

The Carboniferous limestones, which are extensively developed in the northern half of the Mississippi Valley, are in general too soft for profitable use on roads, although, as almost anything is better than miry ways, it may in some places be advantageous to use them.

Here and there in the great section of rocks displayed in this part of the country considerable sections of quartzite occur. Thus in eastern Tennessee and in neighboring parts of Kentucky and Virginia a portion of the sub-Carboniferous strata, elsewhere of a limy or clayey nature, has a quartzitic character, affording materials tolerably useful for roadmaking. The fragments from it mat together in a rather firm manner, and while they grind up beneath the wheels, they serve as well for pavement as any deposits of their general nature. In northwestern Iowa and southwestern Minnesota, as Mr. W. J. McGee informs me, an ancient quartzite, probably of Algonkian age, is coming into extensive use as a source of road material in and near the towns of Des Moines, Cedar Rapids, Sioux City, and Council Bluffs. This rock is said to be very hard and wheel-resisting. It is personally unknown to me, but the reports concerning it indicate that it may have a high value.

Where, as is not infrequently the case, the limestones of this valley, especially those of Carboniferous age, contain segregations of chert which are left on the surface as the lime leaches away, the deposits of this flinty material are often considerable in amount and may have a decided value for roadmaking.

By far the greater part of the Mississippi Valley to the north of the Ohio and the Missouri is deeply covered by deposits of detritus which were brought into position by the glacier of the last ice epoch. The greater part of this material is of a clayey nature, or is composed of other fragments too fine for use in road construction; and this sheet makes the lower-lying hard rock inaccessible. In the greater part of the prairie district and in much of the timbered country to the east the limestones and other rocks which might serve for roadmaking are accessible only by shafts and would have to be won by deliberate mining, a process which is too costly to be thought of.

Fortunately, while the drift makes access to the bed-rocks impossible, it affords in itself, in the most of the fields where it is found, an abundance of pebbly waste in the form of naturally washed gravels, or in a state where the fragments are commingled with clay under conditions which make it possible to win the pebbles by a simple washing process. In some cases the naturally washed gravels have, on account of the presence of iron or of lime, a sufficient binding quality to make them serviceable in roadmaking without further treatment; in other cases it will be necessary to use only the larger pebbles, say those of an inch or more in diameter, first preparing them for use by a breaking process. As these gravelly materials, especially those which have been washed free of clay, must be the first resort of the roadmakers in this part of the country, I have sought from Mr. Frank Leverett, of the U. S. Geological Survey, the results of his extensive explorations in the States of Illinois, Indiana, and Ohio. As Mr. Leverett has been engaged in a careful study of the drift deposits in these and other States in the West, the information which he has to give is of peculiar value.

As regards the gravel deposits of Illinois, Mr. Leverett furnishes the following statements:

Gravel is sufficiently abundant for roads in the following-named counties: McHenry, Kane, Dupage, northwestern Will, and northern Kendall, where it appears usually in the form of knolls, associated with the moraine. In the northern portion of Ogle County there are a long esker and several knolls which afford that portion of the county plenty of road material. In the eastern part of Winnebago County the glacial terrace along Rock River affords an abundance of gravel. Aside from this limited area Illinois is poorly supplied with gravel. There are, however, in nearly every county within the bounds of the Shelbyville moraine gravelly knolls, either associated with the moraine or on the intermorainic tracts, which furnish gravel for road purposes for the townships in which they happen to occur. There are also small amounts of gravel along the Wabash near the southeastern boundary, on the Embarras in Cumberland, Jasper, and Lawrence counties, and along the Illinois in Peoria, Fulton, Tazewell, and Mason counties.

Indiana is particularly fortunate in its supply of gravel. Nearly every county north of a line passing through Parke, Putnam, Morgan, Johnson, Bartholomew, Decatur, and Franklin counties has gravel conveniently placed for use on its roads.

In Ohio the boundary of the district in which gravel is abundant and extensively used is as follows: On the north, Van Wert, Putnam, Hancock, Seneca, and Huron counties; on the east, Richland, Knox, Licking, and Fairfield counties; and on the south, Ross, Highland, Clinton, Warren, and Butler counties. At a few other points in Ohio gravel is sufficiently abundant for roads, especially in the interlobate moraine in Stark, Summit, and Portage counties, and in the moraine extending from east to west through the southern parts of Wayne and Ashland counties and the northern part of Holmes County. Gravel is also abundant along the headwaters of the Muskingum, which flows south from the glaciated district. It is less abundant along the banks of the Ohio River, though deposits are not rare along that stream.

In northwestern Pennsylvania there is not much gravel except in the lowlands, but these lowlands afford an inexhaustible supply, so distributed as to make it readily accessible to much of the upland country.

In addition to the foregoing statements of Mr. Leverett it would be well to note the fact that all the streams flowing from the glaciated district southward beyond the boundaries of that field contain, in practically all cases, quantities of gravel in their beds, and there are generally large amounts of the material beneath the alluvial plains on either side of the river beds. It should be observed, however, that in all cases the gravel of the terraces which border the streams is covered over by a deposit of finer materials, so that the pebbly matter is revealed only by excavation, either that effected by the stream in its swayings to and fro or that made artificially.

The deposits of gravel along the channels flowing from the glacial belt are continued as far as the junction of the Ohio and Mississippi rivers, and may, on search, be found along the main streams. The tributaries which enter the Ohio from the south, flowing from a region which was not overlain by the ice, do not afford such gravelly deposits. South and west of the Kanawha River the ice-sheet passed south of the Ohio at only one point, viz, at Cincinnati, where it extended for a mile or two into Kentucky. The result is that the gravels found along the margin of the river lie mostly on its northern side.

In the section between Cincinnati and Louisville there are occasionally beds of course gravel lying in the terraces at considerable heights above the level to which the waters of that stream at present attain. These accumulations were formed before the last glacial period. They are generally firmly cemented by lime, and the greater portions of the included fragments are of limestone. It is uncertain whether these ancient pebbly beds have any value as sources of road materials.

In closing this general account of the roadbuilding materials of the Mississippi Valley it may be well to note the fact that no other part of the United States so much needs a careful study of its materials fitted for highway construction as this extensive and fertile district. The annual tax which poor roads impose upon the agriculture of this field is a very serious hindrance to the welfare of its people. We can not expect it to be lightened except by the collection and dissemination of knowledge concerning the distribution and structure of those rocks which may prove serviceable to the roadmaster.

In the region within the basin of the Great Lakes the problems of highway building are made the simpler by the cheapness with which suitable materials may be conveyed by water transportation. In the northern peninsula of Michigan and the neighboring parts of Wisconsin and Minnesota there is a great amount and variety of good roadbuilding stones. In fact, no other portion of the continent, so far as known, has within a like area a better supply of such materials. These can be carried at comparatively small cost to all the shore lands of the Great Lakes system. When the canal from Chicago to the Mississippi now under construction is completed, it is probable that the trappean rocks and the low-grade but hard iron ores of the Lake Superior district will be transported to many points on the Mississippi River system.

From Prof. C. R. Van Hise, of the U. S. Geological Survey, I have the following statements concerning the roadbuilding materials of Wisconsin. As the remarks apply to several other States about the Great Lakes which may draw their roadbuilding material from Wisconsin, I shall give them without abbreviation:

The geological formations from which road material is drawn are the pre-Cambrian crystalline rocks and the Lower Magnesian, Trenton, Galena, and Niagara limestones.

In the large Archean areas of the north there is an indefinite supply of crystalline road material, but on account of the expensive transportion little material is drawn from this source, the only locality of which I know being Pike, on the Marquette and Northern Railway. Here a large amount of granite is quarried and shaped into paving stones.

The outcrops of pre-Cambrian in the Paleozoic areas to the south are more largely used. The positions of these isolated masses are indicated by the State Geological Atlas of Wisconsin. The latest description of them is in the Tenth Census, Vol. X, Building Stones, pp. 234–244. This account is mostly compiled from Irving's Wisconsin report. Some of the more important localities are as follows: Montello, which furnishes a considerable quantity of granite for block pavement; Moundville, which furnishes quartz-porphyry for a similar purpose. Quarries have also been opened in the Marcellon quartz-porphyry, in the Marquette quartz-porphyry, in the Berlin granite-porphyry, and in the Mukwa granite, but I do not know that these have been used for roadbuilding. However, for macadam purposes the most important crystalline rocks are the quartzites of Baraboo and Waterloo. Because of its brittle character this material is readily broken up into all grades of macadam material, and is extensively used in cities as a top dressing to limestone macadam. The combination makes a very durable street. The Waterloo quartzite is also cut into block paving stone.

The cheapest source of macadam for the common roads is the limestone. While the Magnesian, Galena, and Trenton limestones in many places are not adapted for building stones, they are always hard enough to furnish a good macadam, which will wear for many years except for heavy street traffic. The distribution of these limestones can readily be seen from Chamberlin's general geological map of the State. Wherever there are cities upon or near these limestone formations, those deposits are drawn upon for macadam purposes.

As yet, however, macadam has been very little or not at all used for country roads. In some places the roads extending into the country from cities are macadamized for a greater or lesser distance. The standard material for dressing the country roads is glacial gravel, which in many localities is of a medium degree of coarseness. This material, when intelligently used (but this is not often), makes a very fair country road.

CORDILLERAN DISTRICT.

In general, the amount of energy which has to be expended on the highways of a country, whether in constructing or maintaining the ways or in conveyance over them, is proportionate to the measure of topographic relief which exists there. In a region of great heights the possible roads between points which need to be connected are necessarily much longer than those in the plains. It is true that in the fertile prairies the division of the land into square pieces for purposes of sale has led to the general use of zigzag ways which follow the boundaries of farms, so that the roads on the fertile plains of this country are much longer than is necessary. In a mountain district the length is enforced by the need of placing the way through the meandering valleys. Moreover, the cost of constructing and maintaining a good road on steep grades, such as are inevitably encountered in regions of mountainous relief, is necessarily much larger than on level lands. It may in general be estimated as twice as great. On these accounts the highway problems of the Cordilleran district are of great moment.

There is yet another set of reasons why all matters relating to roads in the high country in the western part of the United States need immediate attention. On account of the peculiarities of soil and of mineral stores, the industries of that region are in a position where their effective development demands a large amount of transportation. The fertile areas are interspersed among the sterile lands, while the under-earth resources are generally placed at a distance from tillable lands. The result is that the mineral stores have, in most cases, to receive a large amount of carriage before they are brought to market, while the miners have to be supplied with food and other necessities by means of an extended transportation. In a word, it costs more in the way of carriage to do business in the Cordilleras than in any other part of this country. It is therefore of the utmost importance that the burden of the road tax should be made as small as possible.

Although we now have a tolerably good knowledge of the geological structure exhibited in the country between the eastern face of the Rocky Mountains and the western shore of the continent, the detailed structure of the region has only here and there been worked out. As the geologists who have done this arduous work have been pioneers in the field, working generally far in advance of civilization, they have naturally paid little attention to the rocks which may be made useful in road-building. In fact, all such matters have only recently come to have an important place in the minds of those who study the resources of the earth. I have personally seen but a small part of the Cordilleran district, and have to confess that, in common with the other men of my craft, I have paid but little attention to the road materials of the fields which I have studied.

The reports and maps of the Cordilleran district show, in a general way, yet clearly, that the region contains numerous localities of lavas and dikestones which are well fitted for use in road construction. It will be impossible in the space of this report to note the position of these or other suitable materials, but a reference to the general geological map prepared by the U. S. Geological Survey will, to a certain extent, show the reader the positions of the large fields of igneous rock. The innumerable dikes and other possible sources of supply of rock for road construction will be indicated on the detailed maps which the Survey is now preparing.

As is the case with all great mountain systems where in the process of upheaval and erosion the newer rocks are extensively worn away and the older revealed, the Cordilleras exhibit a great many districts of crystalline rocks, such as the granites. Where the dikestones and lavas are wanting it is generally possible to obtain these crystalline granitic materials from their bed places, or from the river deposits of gravel or the glacial accumulations of fragmental stone which have been worn from them.

From Mr. George H. Eldridge, of the U. S. Geological Survey, I have some notes concerning the stratified rocks which may serve in road-building in the Cordilleras, the substance of which I shall now give.

Above the crystalline rocks in the eastern portion of the Rocky Mountains, especially in Colorado, there is a tough quartzite, probably of Devonian age, which has been especially observed in the vicinity of Manitou. This rock will serve very well for macadamizing. The Paleozoic limestones of the same region are of an unusually hard character, and therefore of promising nature. Of these the sub-Carboniferous or Blue limestone is extensively distributed, and is probably of the best quality.

There is another quartzite, probably of Triassic age, occurring at the top of the well-known Red Beds which is likely to afford valuable road material. It is already in use in the region about Denver, and has been shipped from that district for considerable distances to the east.

Concerning the road materials of California, I have the following notes from Mr. J. S. Diller, of the U. S. Geological Survey:

The roadbuilding materials of that region, excepting the basalt, granite, and fine stream gravel, are obtained, so far as I have observed, from the limestones, quartz veins, and flinty beds of the Auriferous slate series. This series is composed of small lenticular masses, and is therefore chiefly of local interest as a source of such material as may be used in roadmaking. Nevertheless, the limestones of various ages—Silurian, Devonian, Carboniferous, Triassic, and Jurassic—are arranged in interrupted belts which can be traced for considerable distances, and occasionally occur in large masses near the railway, so as to be available for transportation. This is true of the Devonian limestone 3 miles southwest of Gazelle, in Siskiyou County, and the Triassic limestones on the stage road to Big Valley, about 40 miles northeast of Redding.

In northern California the large masses of granite and diorite are, in most instances, not conveniently located for transportation, like that of middle California, near Rocklin, on the Central Pacific Railroad, but the long lava-flow which has followed for 50 miles down the canyon of the Sacramento River lies all the way near the railroad and could supply a large demand.

The siliceous slates of Golden Gate Park are used in San Francisco; but nowhere else, so far as I have seen, is material of any kind extensively employed in macadamizing.

It will be observed that the statements made in this report concerning the stones suitable for roadbuilding which occur in the Cordilleran district are more limited in quantity and value than those given for any other considerable portion of the United States. In this presentation, as elsewhere in the report, it has seemed best to limit the statements to the few facts which have been fairly well established. It is important that by this and other writings roadmasters should not be led to the trial of rocks which, although they on slight inspection appear suitable for roadbuilding, have not been properly essayed. It is evidently better to await the extension of the Survey work over this field, combined with proper experimental tests of the materials, than to risk conjectures as to their value.

REVIEW AND CONCLUSIONS.

So far as the imperfect knowledge now in hand permits the observer to make any general conclusions concerning the condition of the highway problem in this country, we will now endeavor to present them to the reader.

It should in the first place be noted that the larger part of the United States is characterized by great seasonal variations in those climatal features which most affect the conditions of carriage roads. There is prevailingly an alternation of heavy rainfall and protracted drought. In times of rain the roads are subjected to a deep penetration of water and serious washings. In the dry seasons the upper surface becomes powdery and resistant to wheels, and either blows away or is brought into the condition of mud when the ground is wetted. These conditions make high-grade roads peculiarly necessary, but also make their maintenance costly.

Another climatal feature, namely, the great range of temperature, is a considerable disadvantage to our roads. Beneath unimproved ways a deep bed of frozen ground is formed in winter, or perhaps repeatedly formed, and during the period when the frost is coming out, which often lasts some weeks, such unpaved roads are generally unfit for use. It often happens, particularly in the prairie States, that road transportation is nearly impossible for from thirty to sixty days in the spring season. Even on the paved ways the range in temperature, which in the pavement may often amount to nearly 150°, brings about an expansion and contraction which tend to weaken and even to break up the road.

Another disadvantage to be encountered in the effort to improve the condition of our roads arises from the fact that nearly half the area of this country—and that part of it in which inheres perhaps nine-tenths of its crop-giving value—is very ill provided with materials fitted for highway construction. To obtain good roads in this field, where the foundations of our national prosperity must always lie, it is necessary to bring the work of construction to a point which can be attained only by a close and thoroughgoing inquiry into the relative qualifications, cost, and modes of use of the various kinds of stone and other materials which may be employed in highway construction. To obtain and diffuse this information is manifestly a most serious and important task, one which can be properly accomplished only by the aid of the Federal Government. As before noted at various points in this report, in the great agricultural districts road materials can be supplied only by the distant carriage of suitable rocks. On this account State surveys, which are necessarily local in their nature, can not properly do the needed work.

Certain peculiar conditions in the economic development of this country, as well as in its system of government, have served to keep our people in a singularly backward state in all that regards the lore of road-making. It may seem to the uninitiated a simple matter to construct a good road, particularly where good materials for the work are readily accessible. In fact, however, as a study of the history of European roads clearly shows, the construction of such roads depends upon a very accurate application of a large body of knowledge, which has been obtained either by costly practical tests or by cheap laboratory experiments. In the Old World states where good roads exist their construction is always under the control of engineers who for generations have been gathering their experience. We can not afford to wait for such a gradual increment of knowledge as has been won in the Old World. The only shorter way to the end is by the institution of a system of surveys and reports, with appropriate maps, by which our road-masters may, as quickly as possible, be put in possession of the required knowledge as to the nature, locality, and mode of treatment of the substances available for use. With this provision made, we may safely trust to the sagacity of our highway engineers for the rest of the work.

It appears to me very desirable that our railway authorities should be brought to see how important it is for the development of their ways that they should favor the transportation over their lines of materials to be used in highway construction. The greater number of roads in this country are, in effect, branches of one or more railways. Cheapness of carriage over these roads is as important to the ironed line as though they were traversed by the locomotives. So far as I have been able to learn, only a few of the railways in this country have shown a disposition to foster the betterment of highways by fixing the charge for the transportation of materials to be used in their construction at the actual cost of carriage.

THE POTOMAC FORMATION.

BY

LESTER FRANK WARD.

CONTENTS.

ILLUSTRATIONS.

THE POTOMAC FORMATION.

By Lester F. Ward.

INTRODUCTION.

The name "Potomac formation" was first used by Mr. W J McGee in 1885.[1] This designation was intended to cover only certain deposits in the States of Virginia and Maryland belonging to the Coastal Plain and lying upon the crystalline rocks of the Piedmont region. It is the same that had been already at that time the subject of somewhat prolonged investigation by Prof. William M. Fontaine, who discovered in it a rich fossil flora and obtained the abundant material for his great work on the Flora of the Potomac or Younger Mesozoic of Virginia.[2] Long prior to this Prof. W. B. Rogers had distinguished this formation in Virginia from the one on the west, to which the Richmond coal field and the Red Sandstones belong. The latter of these formations he supposed to be Jurassic and referred it to the Lower Oolite, chiefly on the evidence of the fossil plants from the Richmond coal field, which had been examined by Bunbury and were thought by him closely to resemble those of the Oolite of Yorkshire, England. The more eastern formation was called by Rogers the Upper Oolite, but its boundaries were very imperfectly determined. In Maryland the iron-ore clays, which have been so long a valuable commercial resource of the State, were recognized by McGee and Fontaine to form in some sense a prolongation of the Potomac formation, but as the Virginia beds chiefly consist of a coarse sandstone, or loose sand, while those of Maryland consist of a red clay, the latter were regarded as later in their date of deposition, and the Potomac formation was therefore divided into a "lower sandstone member" and an "upper clay member."

I began my investigations into the geology and paleontology of the Potomac formation in the year 1885 by joining a reconnaissance made by Messrs. McGee and Fontaine, in which a large portion of the area included in this formation, extending from Baltimore, Md., to Weldon, N. C., was passed over and subjected to somewhat careful study. My

[1] Report of the Health Officer of the District of Columbia for the year ending June 30, 1885, Washington, 1886, p. 20.

[2] Monographs of the U. S. Geological Survey, Vol. XV, Washington, 1889, text and plates.

interest was then chiefly in the fossil plants, as it was also in the year 1886, when, in company with Professors Fontaine and F. H. Knowlton, a collecting tour was made in a steam launch along the bluffs of the Potomac and James rivers, during which large additions were made to the collections of fossil plants. I did not commence the serious study of the stratigraphical relations of these plant beds, and of the rocks in general which make up the formation, until the spring of 1891, when, having completed the work of correlation, from the standpoint of paleobotany, of all the older plant-bearing deposits of the United States, including the Trias, to which I was obliged to refer the Richmond coal field, now sometimes called the Newark system, I began for the same purpose the study of the next succeeding plant-yielding horizon, viz, the Potomac formation. I very soon discovered that the stratigraphical relations of these beds were so imperfectly known that it was impossible to proceed without first making a thorough investigation of the whole subject from the geological point of view. Being well acquainted with the flora, it was clear to me that it must represent a number of distinct periods separated from one another by long intervals of time. I found that the formation had thus far been treated, with the abovementioned exception of its division into two members, as representing practically one period. This was inconsistent with the paleontological evidence. Knowing that the exposed portion of the formation lay between the crystalline rocks on the west and the series of Cretaceous and Tertiary deposits, chiefly marine, on the east, which latter dip coastward and lie regularly imbricated upon one another, it seemed to me altogether probable that if the Potomac formation possessed distinct members, representing different periods of time, or separated by important erosion planes, these several members would also dip coastward and lie imbricated over one another, so that the exposures along the western or landward margin would represent the earlier periods of deposition, and exposures farther eastward, or coastward, would represent successively later periods of deposition.

I therefore began my stratigraphical studies upon this theory, and have conducted them from this point of view during a period of three years. As I advanced with the work I became more and more firmly convinced of the correctness of this position, and the results at which I have been able to arrive—due in the main, as I feel sure, to the employment of a correct hypothesis—are so important that at the risk of seeming to make unsupported assertions I have felt impelled to embody the more general of them in the present paper, in which it will be obviously impossible to give the detailed evidence which has led me to the conclusions stated.

In order, however, that it may appear that these conclusions are based upon actual observations, it seems necessary to give a brief review of these observations. They have not been confined to the States of Virginia and Maryland, but have been conducted upon the more general theory that the formation which was first laid down upon the ancient floor could not in the nature of things be thus limited, but must have been, originally at least, coextensive with the Coastal Plain, not only on the eastern flank of the continental uplift, but also entirely around its southern border. Though it was not to be expected that it would be found at all points, it was to be expected that it would be found at a sufficient number of points to make it possible to trace it throughout the greater part of its extent.

Involved in this hypothesis was the assumption of the continuance of the formation northeastward through the States of Delaware, Pennsylvania, and New Jersey to the Raritan or the Hudson, and the only homologue in those States seemed to be the Plastic Clays of which the reports of the State geologist of New Jersey have given such an exhaustive account. As it was evident at the outset that the red clays of Delaware were simply a continuation of those of Maryland, the conclusion could not be resisted that those of New Jersey were a still further continuation of the same. The Amboy Clays, so called, had already been carefully studied by Dr. J. S. Newberry from the point of view of the fossil flora, and as early as 1884 he had brought to Washington and permitted me to examine a set of plates illustrating this flora. At the time I commenced my investigations Dr. Newberry's Monograph of the Flora of the Amboy Clays was far advanced, and little more was done upon it before his death in 1892. From considerations of this kind I was led to suspect that this formation might have a still greater northeastern extension, and in 1889 I commenced a systematic investigation of this question by an expedition, with a view to making collections, on Marthas Vineyard. Mr. David White accompanied this expedition, and after a somewhat careful examination of the entire island, as well as of the still more northeastern islands of Tuckernuck, Muskeget, and Nantucket, we finally settled down to a thorough study of the west end of Marthas Vineyard (Gay Head, Nashaquitsa, etc.) in search of plant remains, a very few of which had previously been found by Hitchcock and others. The work of collecting I left to Mr. White, who spent the greater part of the season there and succeeded in making a large collection of fossil plants from the variegated clays hitherto supposed to be Tertiary, which proved to consist chiefly of Amboy types, thus conclusively establishing the hypothesis with which we set out. The clays themselves were also discovered on the island of Nantucket, and Mr. White was able to trace them westward to Long Island, where he also made a collection of fossil plants.

In the expedition above mentioned, in which I accompanied Mr. McGee and Professor Fontaine in 1885 through the State of Virginia, the formation was believed to be traced as far south as the Roanoke. Very little is known of it in the States of North Carolina, South Carolina, and Georgia; but in Alabama the Tuscaloosa formation occupies the same stratigraphical position, resting upon the Carboniferous. This formation nad been, I believe, uniformly regarded as Lower Cretaceous. In 1888 Professor Fontaine made quite an extensive collection of fossil plants from several localities in the vicinity of Tuscaloosa. These were sent to me and I made a careful examination of them. In all but one of these localities the specimens consisted almost exclusively of dicotyledonous leaves, and I was able to identify a number of them with Amboy Clay forms. In one locality, however, there were numerous conifers, and the dicotyledons were of more ancient types. After finishing the examination of these plants I felt under the necessity of visiting these localities and making further observations upon the Tuscaloosa formation. This I did in the spring of 1892, in company with Dr. Eugene A. Smith, State geologist of Alabama. This expedition was highly successful and resulted in large additional collections. We crossed the formation and endeavored to work out, to a limited extent, its internal relations.

I had already made, in the summer of 1891, in company with Prof. R. T. Hill, an expedition to Texas and southwestern Arkansas, for the purpose of studying the Trinity group, which also has the same stratigraphical relations and rests upon the Carboniferous. One important locality for fossil plants was discovered and a good collection was made. These plants correspond quite closely to the most ancient Potomac forms, such as are found on the James River at the Dutch Gap Canal.

With this general grasp of the subject as a whole, in May, 1892, I resumed the detailed study of the formation in Virginia, Maryland, and farther north. In the greater part of this I was assisted by Mr. David White. The general plan adopted was that of crossing the formation at as many instructive points as it was possible to select, for the purpose of describing all variations that were found to take place in passing from its landward to its coastward margin, and making careful sections at these points. Without here entering into the details of this expedition, I may say in brief that the principal sections thus made in their order from south to north, were:

1. Section of the James River from some distance above Richmond to City Point.

2. Section of the Rappahannock River from above Fredericksburg to the Marl mill at the Eocene contact.

3. Section of the Accokeek Creek from near Mountain View to Indian Head.

4. Section across the formation at Mount Vernon and Fort Washington.

5. Section on the Potomac at Washington. (The entire region in the vicinity of Washington has been explored in its minutest details.)

6. Section through a portion of Prince George County, Md., beginning near Mount Pisgah church and terminating at Brightseat.

7. Section along the Patuxent River from above Laurel to Priests Bridge.

8. Section across the belt from its northwestern margin near Annapolis Junction on the Baltimore and Ohio Railroad, to Round Bay on the Severn River.

9. Section along the Patapsco, from Relay to Bodkin Point, at its mouth.

10. Section through the city of Baltimore. (The entire region surrounding the city of Baltimore was exhaustively studied, and numerous local sections were made.)

11. Section along the Chesapeake Bay, on the eastern shore, extending from the Baltimore and Ohio Railroad to Howells Point.

12. Section in the State of Delaware from Newark, through Christiana, to Delaware City.

13. Section along the Schuylkill and Delaware rivers from some distance north of Conshohocken, through the city of Philadelphia, to below New Castle, Del.

14. Section along the Delaware River from the Triassic contact above Trenton to the Fish House above Camden, N. J.

15. Section in the State of New Jersey from Ten Mile Run in the Sand Hills to Jamesburg.

16. Section along the Raritan from New Brunswick to Atlantic Highlands, N. J.

Careful observations were also made on Staten Island and throughout the clay deposits of northern New Jersey.

After completing these investigations and carefully surveying the literature of the whole subject, including the still unpublished report of Professor Fontaine on the Geology of the Potomac Formation in Virginia, there remained a large number of unsolved problems, or at least questions upon which my conclusions were different from those of others who had worked in the same field. In order to bring about, as far as possible, a harmony of opinion on these questions, I requested Professor Fontaine to accompany me to the principal points which would throw light upon them. After acquainting him with the general conclusions at which I had arrived, we proceeded, in July, 1893, to visit these critical points and discuss them together. Our observations were quite extended, including much of the area from Baltimore and the Severn River to the Rappahannock. The result was a complete harmonizing of all differences and a unity of opinion on all the questions that relate to the area covered. I do not, however, desire to hold Professor Fontaine responsible for any of the statements contained in this paper. In a few cases I have detected errors in our joint observations since they were made which require some modification of the views at which we then arrived. For all statements relating to other parts of the formation I am of course alone responsible, but I wish to acknowledge my indebtedness to Mr. David White for many acute suggestions relative to the proper interpretation of facts.

With these preliminaries I may now proceed to set forth the general nature of the Potomac formation as I understand it.

STRATIGRAPHICAL RELATIONS.

The Potomac formation as thus outlined may be divided into six members, or series, sufficiently distinct to be recognized wherever seen, but not sufficiently distinct to be regarded as geological formations in any proper sense of that term. Taken together they constitute one geological unit or succession of deposits, interrupted only temporarily, and often then only locally. These six series in their ascending geological order may be designated as follows: (1) The James River series, (2) the Rappahannock series, (3) the Mount Vernon series, (4) the Aquia Creek series, (5) the Iron Ore series, and (6) the Albirupean series.

I. THE JAMES RIVER SERIES.

This, as its name implies, is well developed on the James River from Richmond to the Dutch Gap Canal, and also on the Appomattox from below Petersburg to near its mouth, but it is not confined to these rivers and may be seen on the west bank of the Potomac at many points between Mount Vernon and Aquia Creek. From this latter position the normal dip brings it up to the surface some 6 miles west, where it may be seen in the ravines and especially in the railroad cuttings. As seen on the James River it consists of a very coarse gray sand, not distinguishable from, and perhaps the same as, that of the series next to be described. This coarse sand contains a great number of clay lenses and clay balls, the latter of various sizes, while the former sometimes take the form of interstratified deposits extending more or less horizontally through the sand, always bearing evidence of having been worn by the action of water, and often making it extremely probable that they have been moved bodily to a greater or less distance before they ultimately came to rest in the places where they are now found. But some of these clay seams, though always isolated, are too much prolonged to justify the belief that this local displacement can have been very great, and it is possible that some of them may have been deposited in depressions in the sandy bottom of the ancient Potomac sea, and have only had their margins more or less eroded without having been locally disturbed. I am, however, disposed to refer the coarse sands of the James and Appomattox rivers to the Rappahannock series, and to confine the James River series to the underlying clay deposits; but as these clays are often actually embedded in the sands, this would require the assumption that they have all been transported and redeposited. For the smaller clay pellets, clay balls, and clay lenses, this assumption is abundantly sustained; but some of the clay lenses are so extended as to form veritable strata, sometimes 100 feet in length and only a few feet in thickness. Still, even these, wherever they can be traced, are always found to be isolated, with their extremities abruptly worn off, and often possess other evidence of slight local displacement. As the sands themselves contain no fossils, and are always cross-bedded and more or less disturbed, indicating their deposition in rapidly running water, it is impossible to fix their exact stratigraphical position with reference to the clays, and the theory that the latter were deposited first and have been subsequently slightly transported and redeposited seems to conform more closely to the facts than any other. The following diagrammatic section of the left bank of the Dutch Gap Canal, as sketched by me on October 7, 1892, will show the character of these included clays.

It is difficult or impossible to find the absolute base of the formation on the James and Appomattox rivers, and judging from the analogy presented by the exposures along the Potomac, and by the fact that the sands contain so much redeposited clay, the conclusion can scarcely

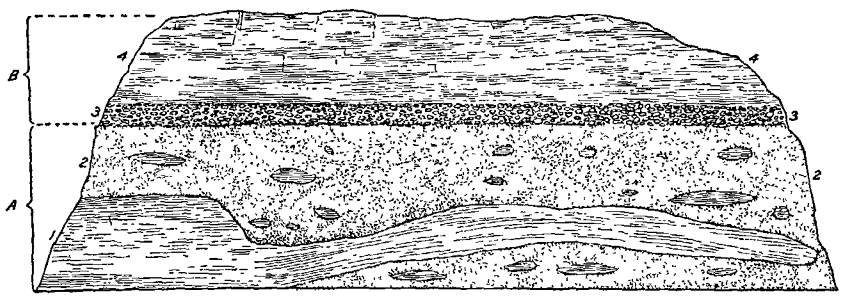


FIG. 1.—Exposure on the north side of the Dutch Gap Canal, James River.

A. Potomac.
1. Clay stratum.
2. Coarse sand and gravel, with clay inclusions.

B. Columbia.
3. Cobble bed.
4. Brick clay.

be escaped that if the base could be reached it would be found to consist of clay, or if not, there would be evidence that it had so consisted, and that the clay had been removed prior to the deposition of the sands.

At Cockpit Point, on the Potomac, on the south side of Gunston Cove, and at numerous other places, heavy beds of sandy clay of a greenish color underlie the sandstones and crop out on the west, as already stated. At one point at least, these clays have been found to contain the characteristic species of the James River series.

The exact nature of these clays has proved difficult to make out. Some of the clay balls included in the sand on the James River, and also in railroad cuttings and other exposures within the city of Richmond, are of a decidedly greenish color, in strong contrast to the greater part of the clay, which is dark, more or less lignite-bearing, or carbonaceous. No vegetable matter has ever been seen in the green clay. The solution of this phenomenon is found in a study of the banks of the Potomac at Cockpit Point, Gunston Cove, and White House Bluff. At the last named of these points the green clays occur in small pellets in the coarse sand, and even in the lithified rock which abounds there, while the underlying clay bed from which these green clays are derived is chiefly below the surface of the water. But at Gunston Cove, on its south side, such beds of green clay occupy the lowest 20 feet of the bluff, and at Cockpit Point they also rise 20 feet from the water level, and are here overlain by typical freestone of the Rappahannock series holding plant remains.

I at first suspected that the green color might be due to glauconite, although it is of a different shade from that of any true greensand known to me. With this provisional hypothesis I fancied that it might represent deposits in relatively deep water, in which, as the Challenger Reports have shown, glauconite can only be formed. I therefore gave to these beds the name of Bathybian Clays. Specimens of these clays were carefully collected from various points and have been submitted to Prof. J. S. Diller for examination. He finds no glauconite in them, and the green color is due chiefly to chlorite and hornblende. They therefore constitute the true basal clays of the Potomac formation, which seems not to have been deposited in the ocean proper at any point east of the Mississippi River. These clays, moreover, weather out bright pink or purple, sometimes with a violet tinge, and great beds of these superficially colored clays are to be seen at the surface along the Alexandria and Fredericksburg Railroad between Bush Hill and the Occoquan, and along the Telegraph Road from the Occoquan southward. They also occur in the bluffs of the Rappahannock 2 miles above Fredericksburg. In fact, wherever the normal dip brings these lowest beds to the surface they present this aspect. As is well known, the crystalline rocks from which the Potomac derives its materials are more granitic and hornblendic in Virginia than in Maryland, which doubtless accounts for the differences of color which prevail in the basal clays of the Potomac formation in these two States. The prevailing color in Maryland is a delicate lilac, and this seems to penetrate so extensively into the beds that the original color is scarcely known. The plant-yielding material of the James River series is, of course, dark and carbonaceous, or somewhat drab colored, and evidently consists of local beds formed either at the summit of the Bathybian Clays or within them; or even, as it would seem, sometimes formed after the beginning of the sand deposits. In fact, it may be said once for all that in the Potomac formation all clays are arenaceous and all sands argillaceous, and the distinction between the argillaceous sands and the arenaceous clays is being constantly obliterated by transitions in the relative preponderance of the one or the other constituent. Close to the landward border, and apparently underneath the purer clays, there often occur more or less stratified beds of hard pack sand with thin clay layers and quartz pebbles. Indeed, the occurrence of rounded quartz pebbles is a common feature of the lower portions of the formation at all horizons. Taking all these facts into consideration, the James River series may be otherwise designated as the Basal Clays.

II. THE RAPPAHANNOCK SERIES.

I have chosen the term Rappahannock to designate this series, in preference to Fredericksburg or Aquia Creek, for the following reasons: (1) The earliest mention that I have been able to find of the principal rock by which this member is characterized is that of Mr. Latrobe in 1784, who called it the "Rappahannock Freestone," and mentioned the fact that the light-house at Cape Henry was constructed of it. In later times it has been more frequently called the Fredericksburg Freestone, or the Aquia Creek Freestone, from the position of the principal quarries. (2) The term Fredericksburg for this series would lead to confusion, in view of the fact that Prof. R. T. Hill has named one of the members of the Comanche series of Texas the Fredericksburg division, and the time will certainly soon come when the Comanche series of Texas will be correlated with the Potomac formation and the several members will be carefully compared. (3) The objection to the term Aquia Creek series is that it is within the vicinity of Aquia Creek that the most typical deposits of a higher series of the same formation are found, and I have therefore decided to give that name to the member designated as "Brooke" by Professor Fontaine.

Although the fossil plants of the Rappahannock series have chiefly been found in clay pockets, lenses, or thin laminæ, the bulk of the material of which the beds are composed consists of a coarse sand, or frequently sandstone, somewhat massive, white or gray in color. This is the "feldspathic sandstone" of Rogers, for which the modern name is *arkose*, and it has been fully described by Rogers, Fontaine, and McGee. It is full of quartz and other pebbles, more or less worn, and usually contains numerous vegetable impressions, casts, or molds, indicating the presence of trunks and branches of trees. On the Rappahannock, and especially at Alum Rock, near Fredericksburg, this feature is very marked. The plant remains sometimes occur in very thin laminæ in heavy beds of this rock, sometimes in large clay lenses occupying depressions in the rock, but sometimes also at the base of the rock proper in a lignite-bearing clay seam.

The typical Rappahannock freestone has been found only between the Rappahannock Valley and that of Neabsco Creek, and it is within this region, so far as I am aware, that all the quarries are located. On the James and Appomattox rivers the coarse sand so closely resembles that of the Rappahannock that there is scarcely any doubt that it is its exact homologue. The important difference consists in the absence of vegetable remains in the form of stems, trunks, etc., as above described. At Point of Rocks, on the Appomattox, these sands are thoroughly lithified. They have for the most part the same color and general character as the nonlithified sands, but at one point I found them much harder, approaching a quartzite, and of a pinkish color. Nonlithified sands also occur in the Rappahannock region, and in fact transitions in the degree of induration occur at all points.

North of Aquia Creek there is another change which brings this material much more nearly into harmony with that of Point of Rocks, on the Appomattox. Here, as in the James River region, the nonlithified sands predominate, but at White House Bluff for a distance of half a mile they form solid rocks, rising some 30 feet above the surface of the river. Here again the vegetable débris is chiefly wanting. From the Occoquan northward, wherever these sands crop out on the surface at the proper distance from the river, they are always soft and show no signs of solidification, and no hard rock has ever been observed by me north of the Mount Vernon estate. North of Hunting Creek and Cameron Run vast quantities of this sand occur in the hills from the river westward for 4 or 5 miles.

It was long supposed that these sands, which were then regarded as the basal member of the Potomac formation, did not extend across the Potomac River into the District of Columbia and Maryland; but it is now known that they do so extend, and although they are somewhat less pronounced north of the Potomac, they may almost always be found occupying their proper position. Here they are never lithified, and are usually much finer in texture, often forming beds of excellent building sand. The clay which they contain is almost uniformly distributed through the sand, often making it nearly a cream color. It is never stratified, in the proper sense of the word, but is usually cross bedded and shows irregular bedding and lenticular inclusions of slightly varying materials. Lines of worn quartz pebbles are almost always present. In the vicinity of Baltimore, especially to the northeast of the city, these sands are very heavy, and have proved a valuable resource in construction.

One of the most constant features of the Rappahannock sands is the presence of silicified wood, large trunks having been exhumed at various points. One of these, disclosed at the excavation of the new reservoir in Washington, was visible for a length of 40 feet, and its lower portion still remained covered. It is in these sands, too, that the remarkable cycadean trunks, first mentioned by Tyson in 1860, were originally deposited. Most of them have been picked up on the surface or embedded in the overlying Pleistocene deposits, and it was until recently the common belief that they belonged to the Iron Ore Clays. This is now known not to be the case.

In the northern portions of Virginia, in the District of Columbia, and nearly everywhere in Maryland these sands are underlain by a clay deposit of greater or less thickness. This clay is sandy, often passing insensibly into sand, and sometimes not occupying its absolute base—that is to say, passing into sand underneath the clay, and especially into gravel deposits. It is usually highly carbonaceous in constitution, and generally contains large quantities of lignite. It is in these lignitiferous clay beds at the base of the sand that most of the fossil plants of these northern sections have been found. It is the plant remains that furnish the proof that these clay beds do not belong to the James River series, but do belong to the Rappahannock series. The greater part of the plants in this series have been found in the Rappahannock region and northward to Cockpit Point. By far the larger number were taken from one large clay lens on the bank of the Rappahannock River within the city of Fredericksburg, but the same types have now been found in abundance in the thin clay seams of the Rappahannock freestone at Cockpit Point. Back from the river, on Potomac Run and at various other points, even in that section, these plants occur in the soft lignitic clays underneath the freestone, the same as at more northerly points.

An excellent proof that there is really no stratigraphical distinction between these underlying clays and the sands is found in the fact that the transition from silicified wood to lignite always occurs here, and in at least one case, on the Neabsco Creek in Virginia, a trunk was found passing through from the one into the other, of which the lower portion, embedded in the clay, was lignitized, while the upper portion, embedded in the sand, was silicified.

In some parts of Maryland, especially within the Patapsco drainage, the Rappahannock series assumes a somewhat anomalous character. This is the region in which the Iron Ore Clays attain their maximum development, and the high rounded hills in which the iron pits occur have been supposed to consist entirely of these beds. A recent careful examination of this region has shown that this is not the case, but that the Iron Ore Clays are confined to the upper portion of these hills and overlie very heavy beds of the Rappahannock series. The iron from these beds, in the form of an oxide, has filtered down through the underlying sands to a great distance, staining them with a deep, lively red color, which often makes it difficult for the unpracticed eye to distinguish between the two classes of beds. Here, also, the Rappahannock sands contain clay seams and large masses of clay. The iron infiltration is arrested at these clay seams and thoroughly permeates them, often imparting to them very brilliant hues. These deeply stained clay layers in the Rappahannock sand under the Iron Ore beds are universally known as "paint stone." They often consist of very sandy clay, upon which the effect of the iron has been to form a more or less indurated crust, sometimes a true rock. At places the quantity of this kind of material is very great and forms large masses which have special economic value and are extensively quarried for the manufacture of paint.

At certain points, especially in the valley of Deep Run, a tributary of the Patapsco, these "paint beds" are underlain by very thick deposits of other materials. The strata next below the paint, for a thickness of 20 or 30 feet, are generally of a coarse gravel, scarcely differing in any respect from the true Rappahannock sands as they occur at many points in Virginia. Below these are the lignite beds already mentioned, only here they attain a very great development, sometimes 40 or 50 feet in thickness. The special peculiarity of these beds is that within them are found embedded immense quantities of nodular ingots of carbonate of iron, the "white ore" of the miners. This ore is greatly superior to the "brown ore" found in the true Iron Ore Clays, and the most extensive and valuable of the iron mines of the State of Maryland are those of the white ore, or "steel ore," as it is sometimes called, in the dark, carbonaceous, lignite-bearing clay of the Rappahannock series, 50 to 75 feet below the base of the Iron Ore Clays.

Recent careful investigations in this and the surrounding regions have shown, with scarcely any possibility of doubt, that the cycad trunks of Maryland, now so celebrated, and of which a very large collection, in addition to those previously known, has recently been made, uniformly come from the upper portion of the paint beds, close to the base of the Iron Ore Clays. A large number of these trunks have been traced with great certainty to this particular horizon, and the exact position of one of them, at least, has been determined. The greater number, however, have been found in the possession of the inhabitants of the district, and it has been necessary to depend to a great extent upon their testimony as to the precise location in which they were found. An exhaustive report upon the whole subject of the cycadean vegetation of the Potomac formation is now being made, but the general conclusion already stated, that the true age of the cycadean trunks is that of the Rappahannock series and not of the Iron Ore Clays, may be safely accepted.

The most northerly point to which I have been able with certainty to trace the Rappahannock series is near Conshohocken, 15 miles northwest of Philadelphia. It occurs here in the form of the lignitic clay, which has a thickness of 8 or 10 feet, lying unconformably upon the blue limestone rock of the Lower Silurian. At Cedar Grove, in this immediate vicinity, there is a large quarry of Trenton marble, upon which Potomac clays, mottled with the various hues characteristic of the Basal Clays, were found resting. At other points in this general region much sand occurs which can not be distinguished from that of the Rappahannock series as shown in Maryland. There can therefore be no doubt that this series once covered these areas, and that we find here a small outlier which has survived the great Schuylkill and Delaware erosion.

III. THE MOUNT VERNON SERIES.

The existence of this series was not discovered until the fall of 1892. It is so inconspicuous that it had been entirely overlooked by all who had previously studied the formation. While it is possible that it may have been originally very general, it seems more probable that it constitutes a somewhat local deposit—at least its homologue has not been found with certainty north of the Potomac River nor south of the Occoquan. It might therefore be regarded as too unimportant to be treated as a distinct member of the Potomac formation were it not for the fact that it has yielded an entirely unique flora, differing decidedly from that of the Rappahannock series below and of the Aquia Creek series above. Its position between these two series is determined without the slightest shadow of doubt. It consists, so far as known, exclusively of stratified clay of a dark chocolate-brown color, fine in texture and very little sandy, highly charged with carbonaceous matter, so much so as to give it a very low specific gravity, and also to render it quite tenacious. The point at which it was first discovered is about a mile below the Mount Vernon Mansion in the eroded bluff of the Potomac River. More exactly, this spot lies directly underneath the high bluff which is known as Rose's Delight, and only a short distance south of the site of the Fairfax Mansion, all within the former Mount Vernon estate. Here, in chocolate-colored clays, as above described, having a thickness of not more than 4 or 5 feet, and lying immediately upon the partially lithified coarse white sand of the Rappahannock series about 8 feet above the surface of the river, I discovered on October 16, 1892, one of the most interesting plant beds that have ever been found in the Potomac formation. I shall return to this subject when treating of the paleontological evidence. This discovery led me to investigate the occurrence of these clays at other points, and I have been able to trace them along the White House Bluff below, where at one point they have a thickness of some 10 feet, and also yield plant remains of the same types as at Mount Vernon. They are also visible on the south side of Gunston Cove; but what is more important, they have been found to continue westward to where the Rappahannock series comes to the surface; and at various points along the Alexandria and Fredericksburg Railroad, opposite those at which they were found on the Potomac, they occur in precisely the same situation, always lying squarely on the sand, with which they form a strong contrast, and here they are at some points 4 or 5 feet in thickness. Unfortunately no fossil plants could be found at these latter outcrops, but the character of the clays, their constitution, color, etc., as well as their stratigraphical position, leave no doubt that they are the same, and the conclusion is justified that this series overlies the Rappahannock series throughout the entire region from the Occoquan to Little Hunting Creek. There is also evidence, as will be shown presently (see Fig. 2), that stratigraphically, at least, the Mount Vernon series is more closely related to the Rappahannock series below than to the Aquia Creek series above. Faint indications of the occurrence of the homologue of the Mount Vernon series have been observed at a number of points in Maryland, and also on the Rappahannock River, but closer study of this question than has yet been made will be required to establish this.

IV. THE AQUIA CREEK SERIES.

Next in importance to the Rappahannock series, both from a stratigraphical and a paleontological point of view, is undoubtedly to be placed the Aquia Creek series. Professor Fontaine, from a study of these two series of deposits, early conceived the idea of an extensive time hiatus between them. The materials of the latter are so obviously derived to a great extent from those of the former that the hypothesis of an important interruption in the general process of deposition at the close of the Rappahannock period is unavoidable. If there is any line separating what I have called the Potomac formation into two distinct geological units that line must be drawn here. The evidence of an important erosion plane at this level is irresistible. How great the time hiatus was is a difficult matter to settle. The differences in the fossil plants of the two series, as will be seen, are very great. But the force of this is lessened by the fact that the fossil plants of the Mount Vernon series are not only very different from those of the Rappahannock series, but seem to contain types as modern as those of the Aquia

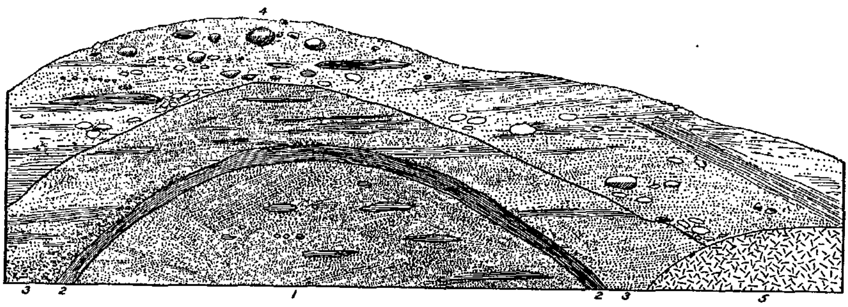


FIG. 2.—Section illustrating the stratigraphical relations of the Mount Vernon Clays. 1. Rappahannock sand. 2. Mount Vernon Clay. 3. Aquia Creek (stratified sand and clays). 4. Franconia gravel, with clay and bowlder inclusions. 5. Decomposed crystalline rock.

Creek series. Quite inconsistent with all this is the further fact that the erosion plane does not occur between the Rappahannock and Mount Vernon series, but between the Mount Vernon and Aquia Creek series. The Mount Vernon Clays adhere snugly to the top of the Rappahannock freestone, and seem to belong to the underlying strata following the contour of the Rappahannock sea bottom in all its undulations, whereas the great unconformity occurs at the base of the Aquia Creek materials. This is clearly shown in the above diagrammatic section, which occurs in a railroad cutting a short distance above Lorton Station (Springman post-office) on the Alexandria and Fredericksburg Railroad, near Pohick Creek.

The materials of the Aquia Creek series, as well as their mode of deposition, are different from those of any of the underlying members of the Potomac formation, although they obviously consist to a large extent of the sands, clays, and gravels of the earlier series. These are redeposited under entirely different conditions, along with other materials from the crystalline rocks on the west. Where the chocolate clays of the Mount Vernon series are not present, and the Aquia Creek deposits appear to rest directly upon the Rappahannock sands, they may be readily distinguished, primarily by their mode of stratification, being rarely cross bedded and almost always distinctly stratified; usually with thin clay seams between those of the sand; but where no such occur the sands themselves consist of distinct strata of different color and consistency. Secondarily they can usually be distinguished by their color, the sand never possessing the clean white and gray coloring so characteristic of that of the Rappahannock series. They are often stained brown or reddish. They are also much finer and softer, less pure, being intermixed with loam. The grains of sand are not surrounded, as in the Rappahannock series, by a coat of kaolin, but the clay contents occupy the interstices between the grains. In some parts of Maryland this last feature is also present in the Rappahannock sands, and here the main distinction is to be found in the features already described.

The fossil plants occur in the clay seams interstratified between the sands. The Aquia Creek material presents an almost endless variety of forms or phases which can not be here described in detail, but those already mentioned are usually sufficient to enable the practiced eye to distinguish these two deposits at a glance wherever seen. Although the Aquia Creek series is usually deposited unconformably upon the Mount Vernon or Rappahannock, still this is not the principal argument for the fundamental distinction which separates it from these. This argument is rather derived from the obvious character of the former as consisting of materials redeposited from the latter.

The Aquia Creek series was not at first supposed to extend across the Potomac into Maryland. The first fact opposed to this view was the discovery by me of an important plant bed on the left bank of the Potomac within the Fort Foote reservation, at what is known as Rosiers Bluff, yielding characteristic plants of the Aquia Creek series, including many species from the typical localities south of Aquia Creek. This member has now been found at many points in the District of Columbia, especially within the city of Washington, where excavations have been made for the extension of streets through the hills that surround the city on the north. Indications of its occurrence have also been noted at a number of points between Washington and Baltimore, and last summer Professor Fontaine and I demonstrated that a part, at least, of the fossil plants that have been collected in the city of Baltimore at the foot of Federal Hill have come from unquestionable Aquia Creek deposits. Farther northward I have not been able to detect it, but careful observation would no doubt reveal it in that direction.

THE FRANCONIA OVERLAP.

By far the most difficult problem that has been encountered in the study of the Potomac formation is that of accounting for the great amount of disturbed sands, gravels, and cobbles that occupy a wide belt on its landward margin throughout the greater part of its length. These materials were formerly confounded with the sand and gravel of the Rappahannock series, which were supposed to occupy the base of the formation. Although very different in character, they were supposed to represent the shore-line, and their irregularity of deposition was ascribed to this position. Later, after the discovery of the occurrence of what was first called the Appomattox formation, now known as the Lafayette, the most of this disturbed material was referred to that period, and is still so designated on the geological maps published by the Survey. No attempt has ever been made to draw the line between the supposed Lafayette and the Potomac deposits which so closely resemble it. I was myself at first disposed to regard it all as Lafayette, but certain facts which became more and more obtrusive as the work went on have led me to think that they may in fact belong to the Potomac. They can not, however, be identified with the materials of the Rappahannock series, and if of Potomac age they were deposited toward the close of the Aquia Creek period. In a great number of cases these disturbed materials are found directly overlying the stratified deposits of that series. They are never found far from the landward margin, and always occupy the surface, or if not the present surface, at least the highest place in the Potomac formation.

These materials may be described as consisting principally of sand, gravel, or cobble, the cobblestones usually much worn and varying in size from that of a hen's egg to that of a cannon ball, very irregularly thrown together and never properly stratified, but exhibiting large lenses and short evanescent laminations, first of one material and then of another, usually showing a great local angle of dip, rapidly alternating from anticlinals to synclinals, often exhibiting the "flow and plunge structure," and in general bearing evidence of having been laid down in turbulent and tumultuous waters alternating with periods of quiescence and having many local eddies. Very large bowlders, scarcely at all worn, of quartz, quartzite, gneiss, and granitic rock are frequently seen, sometimes having a diameter of 2 or 3 feet. There are also clay seams, clay lenses, and sometimes lines of very small clay pellets distributed through the mass. Clay is also sometimes found in large amorphous lumps, as if taken up bodily from the underlying strata and deposited without having suffered any appreciable attrition. These are usually pink, but sometimes of other colors. The smaller pebbles, and sometimes stones of considerable size, are often thoroughly rotten, so that while they appear from the general view like the other hard stones, they are found upon examination to be decomposed throughout, and to have the consistency of mere clay balls. In the caving away of banks by natural agencies these stones are frequently divided in half flush with the wall, leaving one-half attached while the other half has fallen below and been crushed to powder in the talus.

The clays were evidently taken up from the basal materials of the Potomac formation, borne to a greater or less distance by rapid currents, and there redeposited. But, as already remarked, they then constituted a superficial deposit, not having the normal dip of the formation but conforming in all respects to the surface of the country. Although they have their origin some distance over on the Aquia Creek material, upon the beveled margin of which they may be seen lying unconformably, they nevertheless spread out far to the westward, overlapping the belt formed by the Rappahannock sands and the James River clays and forming a broad sheet, sometimes miles in width, upon the crystalline rocks.

I am indebted to Mr. David White for the first suggestion of this explanation of these remarkably enigmatic deposits, and if they belong to the Potomac formation at all they can, I believe, be explained only on his theory. When in July last Professor Fontaine and I visited the extensive gravel pits of the Alexandria and Fredericksburg Railroad at Franconia Station, 6 miles southwest of Alexandria, we here found the most complete exhibition of these interesting materials that is known to occur at any one point, and after a thorough discussion of the theory above sketched we decided to name the phenomenon as a whole the Franconia Overlap.

The Franconia Overlap may be seen in all its protean phases at various points between the Rappahannock Valley and the Delaware, occupying the same position on the landward margin of the formation, chiefly in contact with the crystalline rocks, but sometimes traceable over portions of the Rappahannock and Aquia Creek series. It has been the subject of careful study, but any attempt at a detailed description would carry me far beyond the limits of this article.

I should not like to leave this subject without giving expression more decidedly than I have already done to the lingering doubt which I have never been able to overcome as to whether these deposits were really laid down in Potomac time, or whether they may not after all belong to a much later period, for example, that of the Lafayette. There is absolutely no stratigraphical proof of their Potomac age. No formation older than the Columbia (Pleistocene) has ever been found overlying them. Their resemblance to the true Lafayette, so well exhibited on the other side of the belt, is so close that it is often impossible to indicate a distinction. There are, however, some differences, mostly of degree, but often quite important. The following may be said to constitute the entire evidence that the two deposits are of different age:

1. The size of the cobblestones in the Franconia is generally considerably larger than in the Lafayette.

2. The occurrence of large bowlders, as above described, is, I believe, exclusively confined to the Franconia.

3. The clay inclusions of all kinds, as I have described them, belong, so far as I know, exclusively to the Franconia.

4. The upper part of the Aquia Creek series is often much disturbed, and at some exposures, particularly those on Sixteenth street extended, in the city of Washington, the clay masses actually yielding fossil plants, and for this reason referred to the Aquia Creek series, can with difficulty be distinguished from those above them which we are obliged to refer to the Franconia. In other words, a few points are known at which the Aquia Creek series graduates insensibly into the Franconia.

On the other hand, much of the evidence that was at first relied upon to distinguish these formations has broken down entirely. For example, we find in the Lafayette the irregular bedding and disturbed condition the same as we find them in the Franconia, only less marked. The supposition, too, that decayed pebbles, so abundant in the Franconia, necessarily represent a great age and therefore prove its Potomac affinities is now known to be unfounded, and precisely the same conditions may be seen in the typical Lafayette at points where it directly overlies the latest Tertiary deposit, viz, the Chesapeake. Taking everything into consideration, therefore, the only proper scientific attitude as regards the age of the Franconia Overlap seems to be that of a suspension of judgment. But this much, at least, may be said with safety, that whatever its age it is not susceptible to subdivision. It either all belongs to the Potomac or all to the Lafayette, or, at least, all to the same epoch, and it is not possible, as has been done in the geological maps thus far printed, to refer a part to one and a part to another formation.

V. THE IRON ORE SERIES.

This is one of the best known and best recognized members of the Potomac formation, and yet there has been a great amount of both doubt and error in regard to its precise relations to the strata below and above it. It was early supposed to constitute the entire formation in the State of Maryland, and it was this view that led to the adoption by Messrs. McGee and Fontaine of the term "Upper Clay Member." But, as has been seen, further study has shown that the so-called "Lower Sandstone Member" flanks it for its whole length through that State on the northwest. A still more detailed examination has shown that even in the State of Maryland the Aquia Creek series at least is often found occupying its proper place and the Iron Ore Clays proper are superposed more or less conformably upon that series. The most important locality at which these relations can be seen happens to be the one at which the largest number of vegetable remains in the State of Maryland have been found, viz, at the foot of Federal Hill, in the city of Baltimore; and in a fresh clay and sand pit opened by Mr. Weaver on Jackson street which was visited by Professor Fontaine and myself on July 20, 1893, the following section was measured:

	Feet.
8. Typical Iron Ore Clay	20
7. Blue clay without sand	8
6. Blue, lumpy, and sandy clay	2
5. Dark laminated clay	4
4. Paint stone (considerably indurated, brick-red, sandy clay)	6
3. Coarse kaolinic grit	5
2. Paint stone (deep madder-red, somewhat lithified, arenaceous clay)	1
1. Mottled clay with predominating purple hues; depth unknown.	

In No. 5 of this section fossil plants of the Aquia Creek series are abundant, and in No. 6 some vegetable remains were also found. From all that has gone before it is easy to see that this section admits of the following interpretation: No. 1 is the Basal Clay, probably of the James River series. Nos. 2 and 3 represent the Rappahannock series. No. 4 occupies the position, at least, of the Mount Vernon series. Nos. 5 and 6, and probably also No. 7, represent the Aquia Creek series. No. 8 is the Iron Ore series.

The locality is too far from the shore-line for any of the Franconia materials to occur.

The basal portion of the Iron Ore Clays, viz, those parts lying farthest to the landward side of the belt, consists chiefly of a dull-red clay in which is embedded in the form of nuggets of concretionary origin, varying in size from a few inches to a foot or more in diameter, often elliptical or cylindrical, irregular in shape, or much elongated—the brown iron ore of that region. These have frequently been described and are too well known to require further explanation. The series has along this line, forming a belt of 1 to 2 miles in width, a thickness in places of 100 feet.

There is no difficulty in tracing the landward margin of the Iron Ore Clays, or of determining their contact line below. It is often directly underlain by heavy beds of Rappahannock sand without the intervention of the Aquia Creek series, but it differs so greatly from both that there is never any difficulty in distinguishing it. This, however, can not be said for the upper portion of this member, and it has proved a very serious problem to determine where the line should be drawn between the Iron Ore series and the next series above. Certain it is that in passing across the belt, after traveling a certain distance over the Iron Ore Clays, their distinctive features are ultimately lost sight of and a series of different colored clays and white sands at length takes their place. The color of the next succeeding clay beds is usually a bright purple instead of a dull red, and the Iron Ores wholly disappear. Very little more than this can be said with regard to the boundary of the Iron Ore Clays. One may restrict them entirely to the iron-bearing portion, or one may include in them the non-iron-bearing purple clays on the east. But, as will be seen, these latter alternate with the upper white sands throughout the entire extent of the Albirupean series. I shall therefore make no further attempt at such a boundary.

The Iron Ore Clays have not been made out with certainty anywhere in the State of Virginia, all the red clays on the south side of the Potomac being referable to either the James River or the Rappahannock series and being overlain by the Aquia Creek series. But this by no means proves that the Iron Ore series is not present in Virginia. North of Aquia Creek they could hardly occur on account of the proximity of the Potomac River, which cuts away all the eastern portions of the formation. No Iron Ore Clays are visible along the Rappahannock River, although the James River, Rappahannock, and Aquia Creek series lie normally exposed along its banks, and we find the marine Tertiary deposits overlying the last-named series. If the Iron Ore Clays occur at this point they must lie under a great thickness of marine Tertiary a considerable distance farther east. Only by boring at the proper points could the question be settled. On the James River, as has already been seen, even the Rappahannock series rarely or never comes to the surface, and is seen only in the banks of the rivers, overlain by heavy beds of Miocene. At only one point has the Aquia Creek series been made out in this region, viz, at Deep Bottom, 5 miles below the Dutch Gap Canal, which is the most easterly point at which the Potomac formation occurs. If the Iron Ore series is present at this latitude it must be some distance farther east and deeply buried under the later marine deposits. For my own part I am disposed to believe that this is the case, and that the Iron Ore Clays would be found at many places along a line drawn from Fort Washington to City Point. The evidence as to this is in the fact that the Iron Ore Clay does crop out on the eastern shore of the Potomac. At Fort Washington, close to the water's edge, there are many ferruginous nodules and geodic fragments strewn along the shore and partly embedded in red clays, which are indistinguishable from those found in other parts of Maryland where the Iron Ore Clays are distinctly present, and there is reason to believe that these represent that series, which here passes under the alternating clays and sands of the Albirupean series, so distinctly shown in the celebrated exposure at that place.

VI. THE ALBIRUPEAN SERIES.

The name "Albirupean" was first used by Prof. P. R. Uhler in 1888[1] to designate a series of rocks supposed by him to constitute a distinct formation, and especially characterized by the occurrence of large angular blocks of a bright white color, and very hard, found chiefly upon the surface, like erratic bowlders, but sometimes forming considerable ledges along certain rivers that flow into the Chesapeake Bay. The best known of these are the celebrated "White Rocks," which lie in the mouth of the Patapsco River half a mile from its southern shore. These are very large and present four principal masses huddled together

[1] Proc. Am. Phil. Soc., Vol. XXV, Philadelphia, January 6, 1888, p. 42.

and rising some 5 or 6 feet above the surface of the water. Some of them are not white, but of an iron-brown color, and these are also much softer and considerably decomposed. On the north side of the Patapsco, at the extremity of Back River Neck, is another mass of these rocks, and indeed this entire point is made up of a ledge of them. Here the brown colors predominate. This ledge extends some distance up the neck on both sides of Shallow Creek, where it is seen to very good advantage. There is evidence that these rocks are what is left of an outcrop along a nearly north and south line which may extend for many miles in either direction. Near the head of the Magothy River there is another extensive ledge of similar rocks, and in the vicinity of Marley station, on the Annapolis Shortline Railroad, there are quarries of these rocks which were worked many years ago, but have long been abandoned. Another locality at which the white rocks are irregularly strewn over the surface of a considerable area is some 2 miles north of Collington, on the Pope's Creek Railroad, between that place and Bowie station, on the Baltimore and Potomac Railroad. Here they occupy a meadow and wooded depression and do not seem to form a ledge. Rocks of this class also occur in the Patuxent Valley, especially on its left bank several miles above Hicks's Mill. Near Germantown, northeast of Baltimore, there is another area covered by rocks of a similar character, but both from slight differences in the texture of these rocks and also from their position, there is some doubt as to whether they belong to the same system.

The rocks above described form a very small part of the material of the Albirupean series, but they all appear to belong to it and to constitute simply the thoroughly lithified portion of the purest sands contained in that series. The lithification, however, has gone much further than in the Rappahannock freestone, often constituting a true quartzite, and in some specimens it can scarcely be distinguished from some of the Paleozoic rocks, as for example the Medina sandstone.

As was remarked when treating of the Iron Ore series, the exact origin of the Albirupean series is exceedingly vague, as the transition from the Iron Ore Clays to those included in the Albirupean is by insensible gradations. It is possible that it may be ultimately found best to consolidate them into a single member, but if this is done it is the Iron Ore series that will have to be sacrificed, because, though economically so important and popularly so well known, it is geologically of comparatively little significance.

Speaking generally, then, the Albirupean series may be said to consist of beds of alternating clays and sands, the former predominating on the western and the latter on the eastern margin, at least in the State of Maryland. The belt in this State has a breadth of 7 or 8 miles, often more, and in crossing it the principal material seen on the surface is a yellowish sand, intermingled with ferruginous shales and interspersed with larger bowlder-like rocks, sometimes white, but usually reddish brown. Included in these sands there occur large masses of purple clay, sometimes mottled, often very free from sand and exceedingly tenacious. There also occur dark carbonaceous clays, often plant bearing. Sometimes the clays and sands are laminated and interstratified, constituting what Professor Uhler calls the "alternating clay-sands." The sands, mostly yellowish on the west, often become pure white on the east and furnish the best of building sands. Any of these general phases is likely to occur at any point, but in general the clays predominate in the lower and the sands in the upper portions.

The three most important points at which these various features of the Albirupean series are to be seen are, first, on the Severn River; second, on the south side of the Patapsco River; and third, on the eastern shore of the Chesapeake Bay. In all three of these places all the phases of this series are beautifully revealed, and in comparing these three sections, which are located at considerable distances from one another, it is possible to discover the homologue of any particular feature at all of them. Thus there seems to be one horizon occupying a considerable breadth at which the purple mottled tenacious clays occur in vast quantities. I have denominated this belt the Hawkins Point Clays, from their occurrence at Hawkins Point on the lower Patapsco, where they form an extensive cliff 40 feet in height, with a width along the shore of nearly half a mile toward Swan Creek. Starting with this, we may trace it southward in imagination to where it crops out on the Severn River, 2 miles above Round Bay, and similarly carrying it northward across the Chesapeake we find it presenting precisely the same conditions at Red Point, at the mouth of the Northeast River.

Above this are the alternating clay-sands, some of which present beds of highly carbonaceous clay holding fossil plants, and others a chocolate-colored very sandy clay, also plant bearing. Both these features occur at Round Bay on the Severn River. At Grove Point on the Chesapeake at the mouth of Sassafras River the second of the above-mentioned classes of the plant-bearing deposits has yielded quite a rich flora, the plants being about the same as those collected on the Severn. At Bodkin Point, on the western shore of the Chesapeake just below the mouth of the Patapsco, the same beds have also yielded fossil plants of the same types. In all three of these sections the highest plant beds are within a few feet of the marine Cretaceous formation, and this is seen distinctly overlying the Albirupean sands at the water's edge a short distance below the pavilion at Round Bay.

Some difficulty has been experienced in tracing the formation through the State of Delaware. Few exposures occur in that State, but at Christiana there are heavy beds of red clay underlain by a lignite bed, and there is every reason to suppose that these belong to the Albirupean series. The same conditions were also found at the Red Lion Hotel, 6 miles south of Christiana, and they seem to prevail throughout the level portion of the State, but are mostly covered up by superficial deposits. Below New Castle, however, these clays are to be seen on the banks of the Delaware, and rise at one point to a height of 6 feet. They undoubtedly underlie the Delaware River, and have here been taken out in large quantities from the bottom of the river for making pottery. These submerged clays are pure white, having escaped oxidation, but turn red on exposure to the air.

The important problem which a consideration of the Albirupean series brings forward is none less than that of the geological position of the Plastic Clays of New Jersey, otherwise called the Raritan and Amboy Clays, which Prof. W. B. Clark has recently proposed to call the Raritan formation. The principal evidence on this point is paleontological, and must therefore be deferred for the present. I may, however, so far anticipate as to say that the flora of Grove Point, Bodkin Point, and Round Bay contains so many of the types of the Amboy Clay flora that it is impossible to doubt that they all belong to practically the same horizon. We are therefore obliged to consider the Amboy Clays as simply a broadening out of the narrow belt which has yielded these forms at these more southerly points, and when we cast our eyes over the map of these regions we see at a glance that this is precisely what we ought to expect on the perfectly rational assumption that these deposits do not abruptly terminate at the Delaware River, but continue their northeastern trend through the State of New Jersey. We have simply to assume that for some reason the clay marls and overlying marine deposits do not extend so far over upon the formation in New Jersey as they do in Delaware and Maryland, and that therefore the exposed belt of these clays is much wider in that State. A careful examination of the entire series of New Jersey clays from their contact with the Newark system on the west to where they disappear under the marls on the east, on both the Delaware and Raritan rivers, has confirmed this hypothesis at all points. That the broad belt of Plastic Clays displayed along the Raritan River from near New Brunswick to Morgan represents a series of deposits and not a mere trough is too obvious to require discussion, and therefore the strata on the western side at Woodbridge, Milltown, and Sayreville represent a lower horizon than those farther east at South Amboy and Morgan, and I may say here that changes in the flora at these several points abundantly confirm this view.

From Morgan, the most easterly point, the formation may be traced northward across Staten Island and the northern shore of Long Island, and it reappears on Marthas Vineyard in the celebrated cliffs of Gay Head. At all of these points the stratigraphical evidence is strongly supported by paleontological evidence. Along this most eastern line a new phase is seen, viz, the occurrence of concretions in the variegated clays, in the form of hard ironstones, which when broken open are often found to contain vegetable remains in an admirable state of preservation. I am therefore disposed to regard these ferruginous, concretionary beds, extending from Staten Island to Marthas Vineyard, as the very latest phase of the Potomac formation, which I shall call the Island series, although from the similarity in the flora I am disposed to include them, along with the Raritan and Amboy Clays, in the Albirupean series.

The questions will of course be asked, What has become of all the other members of the Potomac formation in New Jersey? Where are the James River, Rappahannock, Aquia Creek, and Iron Ore series? It must be admitted that these are questions difficult to answer. If they were once present it would surely be supposed that some slight traces of them would remain, no matter how great the erosion might have been. Of course there is a possibility that for some reason these beds were never laid down, but this can scarcely be more than a possibility. Assuming that they were once present, how can their absence be accounted for? In the first place, it must be confessed that they have not been diligently and intelligently looked for. If only faint traces of them remain at obscure points, these could only be detected by one who had made the formation a study and who should go on purpose to find them. This has not yet been done. As an illustration of the ease with which such facts may be overlooked, I may again refer to the discovery by Mr. David White and myself, at the point near Conshohocken mentioned above, of just such traces of the old Potomac as may exist in New Jersey. This fact had been entirely overlooked, so far as I have been able to learn, by the Pennsylvania geologists who have so exhaustively studied the geology of that State. We carried Professor Hall's report in our hands as we traveled over this region, and we steered our course by his maps, and yet no Cretaceous is indicated on those maps or mentioned in that report at the point where it was found. Mr. McGee, in traversing this region for the purpose of discoving the Lower Potomac, seems to have found different localities.[1]

On the assumption of the entire absence of the Lower Potomac series in New Jersey, there is one consideration that may, I think, be properly urged in explanation. This is the fact that we have now reached the region of glacial action. It is well known that above the terminal moraine a great amount of loose material that still remains at more southerly points has been planed away by the action of ice. Even the crystalline rocks are decomposed to a considerable depth in the South, and this loose material still covers the harder rocks; but in the North all of this has gone. Such must have also been the fate of all kinds of loose material that lay upon the surface. The Older Potomac strata would have fallen a natural prey to this all-devouring agency, and it may be that the great ice-sheet has succeeded in carrying away the last trace of it over all this region. It will also be seen that this same fact furnishes the explanation of the greater width of the clay belt at these latitudes, for the power that removed the sand and gravel of the Older Potomac was also equal to the removal of a great portion

[1] Cf. Am. Jour. Sci., 3d ser., Vol. XXXV, February, 1888, p. 131.

of the marine Cretaceous and Tertiary deposits which so far overlap these clays at more southern points.

This theory, however, is not sufficient to account for the complete absence of the Lower Potomac at the proper horizon, and we must fall back upon the general assumption which it is necessary to make in studying the Potomac formation, of an oscillation of level at the close of the Rappahannock period, and perhaps also at the close of the Aquia Creek period. As the land rose out of the water the deposits were eroded away, and after it again sank beneath the water the later deposits were laid down upon the new floor and spread out far beyond the margin of the older material. Here in New Jersey we find the clays in direct contact with the Red Sandstones of the Newark system as far west as the Sand Hills and Ten Mile Run. The question is whether farther out in the formation there is any evidence of Older Potomac material underneath the clays. This can be settled only by boring. Fortunately we have some direct evidence on this point in the case of the Jamesburg well, which was completed by Mr. H. F. Walling in 1880 to a depth of 481 feet. A glance at the section published in the annual report of the State geological survey of New Jersey for 1880 (pp. 166–167) shows pretty conclusively that the true Amboy and Raritan Clays were not found below 251 feet. Below this the materials correspond, as nearly as can be judged from borings, to those of the Aquia Creek and Rappahannock series, and possibly they may extend into the James River series. The 60 feet of dark-blue clay ending at 316 feet may represent the Iron Ore series, and the 17 feet of sandstone would seem to belong to the Rappahannock series. The Aquia Creek series may possibly be wanting. The underlying quicksands and clays agree well with much that is known of the James River series.

While speaking of boring, it may be well to mention the remarkable shaft at Fort Monroe sunk by General Humphreys in 1869 to a depth of 907 feet. About 800 feet of this was through the marine deposits, but the last 100 feet or more, judging from the description in Rogers's Geology of the Virginias, page 735, must have been through Potomac material. Professor Fontaine is of the opinion that this was the coarse sand, gravel, and clay of the James River, and it would certainly admit of this interpretation; but considering the great distance (over 50 miles) of Fort Monroe from the most easterly point at which any Potomac has been found, taken in connection with the probability that the upper portions of the formation are represented at most points, it would seem a more reasonable assumption that this last 100 feet consisted of the Albirupean sands and mottled clays, as I have described them.

The limits of this paper will not admit of a discussion of the relations which the facts here presented bear to deposits in other States. I may merely remark, relative to the Tuscaloosa formation, that it seems to present the same relations that are found in New Jersey. The plant-bearing deposits lying close to the northern or landward margin represent, to all intents and purposes, those of the Raritan and Amboy Clays, and contain, as will be shown, many of the identical types. One locality only, viz, that at Snow's plantation, 9 miles below Tuscaloosa, close to the river surface, indicates a somewhat different flora, representing an earlier date. Some of the types here found occur in the flora of the Aquia Creek series, while others are common to the Amboy Clays. It may be, therefore, that we have here an intermediate flora corresponding in age to the Iron Ore series.

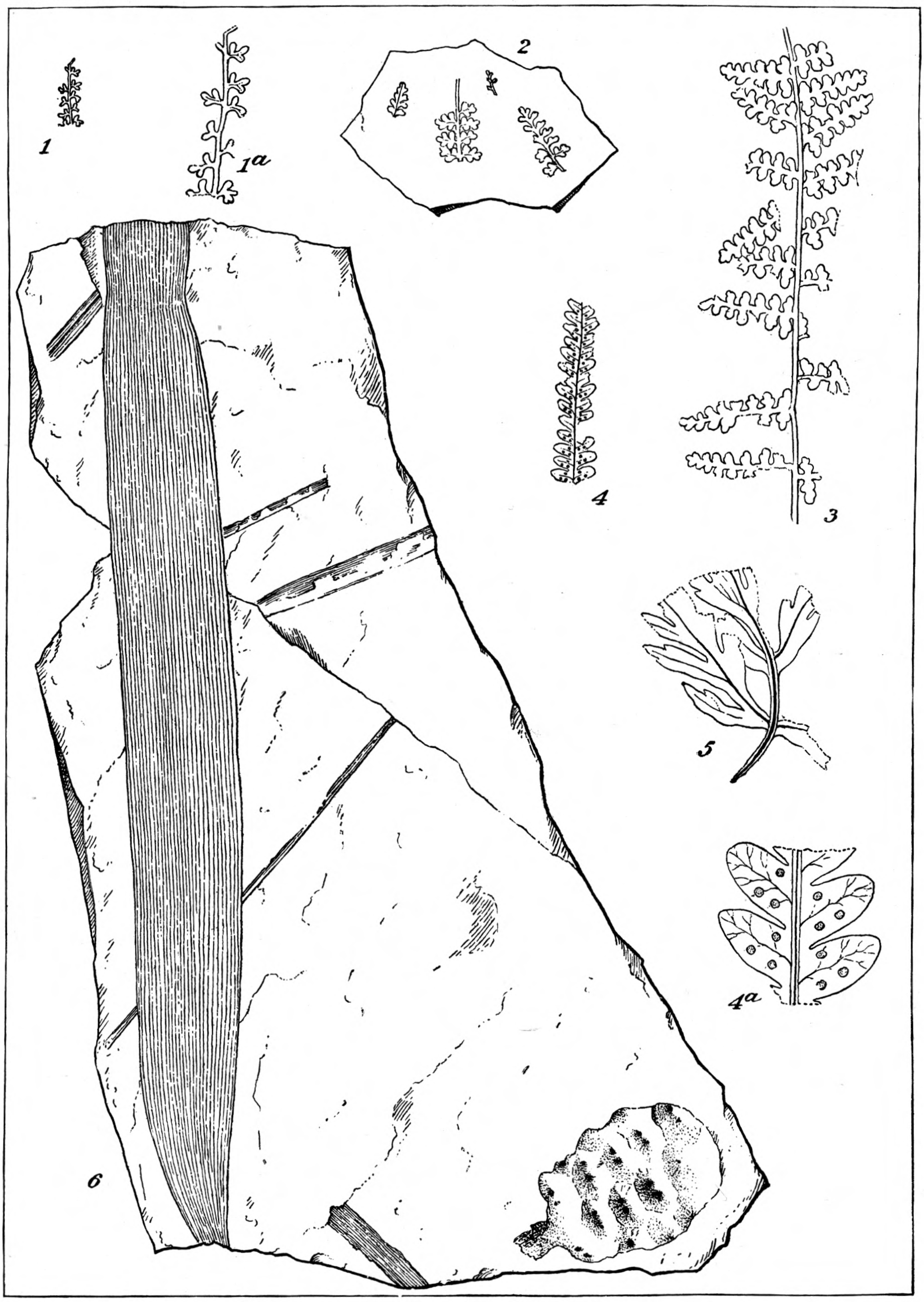
In marked contrast with this is the only florula that has been found in Texas at any horizon that could correspond to that of the Potomac formation, viz, that of the Glen Rose beds of the Trinity division of the Comanche series, which correspond very closely to those of the James River series. In southwestern Arkansas, also, one of the James River species has been determined, and it would seem probable that, generally speaking, the Trinity division corresponds to the James River series.

STRIKE, DIP, AND THICKNESS.

Strike.—The strike of the formation conforms, of course, in a general way to the Atlantic and Gulf coasts. In the Gulf region it is generally east and west, but trends northward in the Mississippi Valley, reaching into Tennessee, and again southward through Arkansas, assuming a more westerly course through Texas. In the Atlantic States it has a direction from northeast to southwest, with, however, many irregularities. Its position is best known in the States of Virginia, Maryland, Delaware, Pennsylvania, New Jersey, and Massachusetts, where it is roughly parallel to the coast. In arriving at the strike in these States, allowance has, however, to be made for the fact already stated, that in Virginia the upper members are covered by overlying marine deposits, while in New Jersey the lower members, if they were ever present, have been eroded away. The real strike is therefore more nearly north and south than a line which should actually follow the margin of the formation as it now exists.

Dip.—Many estimates have been made of the dip in different States, and these vary from 25 to 50 feet to the mile. The former estimate of the State geologist of New Jersey as to the dip of the Plastic Clays was 45 feet to the mile. I have myself made numerous calculations, in most of which it falls considerably below these figures, and 35 to 40 feet would seem to be nearer the truth. Prof. W. B. Clark, in a recent paper, gives the dip of the greensands at between 25 and 30 feet to the mile, which is probably correct; and in fact it should be remembered that in all the deposits of the Coastal Plain the dip diminishes with the age of the deposit.

Thickness.—The thickness of the formation is a much more difficult problem. Estimates have been made by different authors only of certain parts or members separately, as of the Plastic Clays, the Rappahan-



MOUNT VERNON FLORA: FERNS, CYCADACEÆ.

nock series, the Aquia Creek series, the James River series, and the Albirupean series, and not always with a clear conception of their true delimitations. Professor Fontaine has estimated the three principal members in Virginia at 150 feet each. Professor Cook put the thickness of the Plastic Clays at 210 feet in New Jersey, and Mr. Chester at 250 feet in Delaware. Professor Uhler's section of the Albirupean on the Patapsco foots up 500 feet. I am inclined to think that this last is not greatly overestimated. This, it will be remembered, includes the Hawkins Point Clays, which seem to be the equivalent of the Red Clays of Delaware and the lower Plastic Clays of New Jersey.

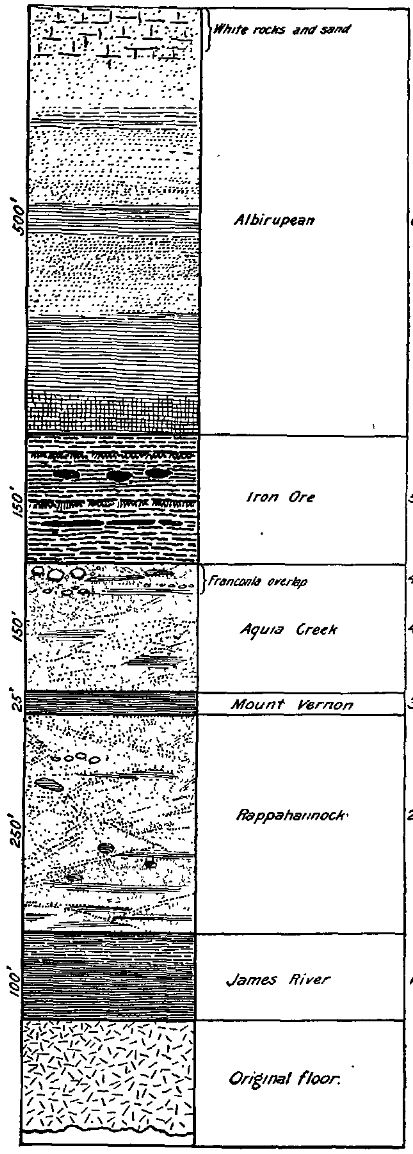


FIG. 3.—Columnar section of the Potomac formation.

In view of the undoubted oscillations of level which have taken place, locally at least, at different horizons within the formation, and the consequent erosion, it becomes impossible to say how much the aggregate of all the deposition would be. It is usually safe to add considerably to any section that may be measured, and the danger is rather of underestimating the thickness than of overestimating it. We may say in general, then, that the James River series probably had a thickness of at least 100 feet, and the Rappahannock series of over 200, perhaps 250, feet. The Mount Vernon series may probably be safely put at 25 feet. The Aquia Creek series is at least 150 feet thick in some places. I do not think that the Iron Ore series, properly restricted, exceeds 150 feet; and I am inclined to accept Professor Uhler's estimate of 500 feet for the thickness of the Albirupean series as I have outlined it. The columnar section, Fig. 3, may therefore represent the thickness of the several members and of the formation as a whole.

Space will not permit a complete illustration of the character of the Potomac formation by means of diagrammatic sections, but the following generalized section (Fig. 4) may serve for all. It assumes what does not, in fact, exist—the occurrence at some point of all the members of the formation at their full thickness, and aims to represent, with of course a greatly exaggerated dip, a complete section across the belt, perpendicular to the strike.

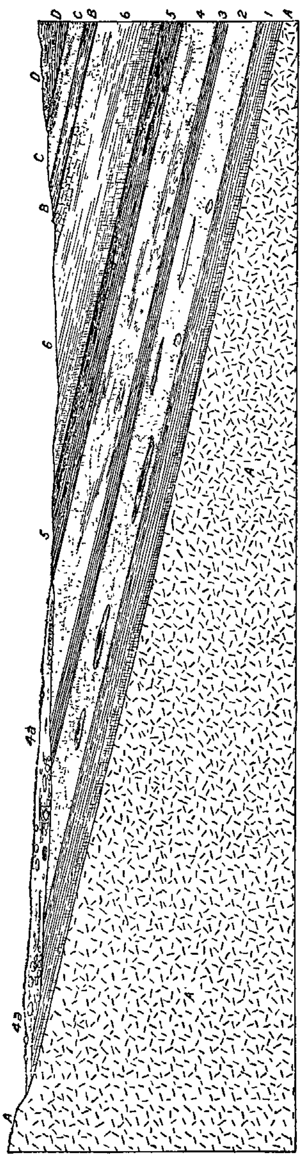


FIG. 4.—General section of the Potomac formation. 1. James River series. 2. Rappahannock series. 3. Mount Vernon series. 4. Aquia Creek series. 4*a*. Franconia Overlap. 5. Iron Ore series. 6. Albirupean series. A. Pre-Cretaceous (crystalline rocks, Cambrian slate, Carboniferous or Trias). B. Marine Cretaceous (Severn or Matawan). C. Eocene. D. Miocene.

The section, Fig. 5, along an east-northeast and west-southwest line beginning near the village of Occoquan, crossing the Alexandria and Fredericksburg Railroad 1 mile below Lorton station, passing through what is known as White House Bluff on the right bank of the Potomac, and terminating at Fort Washington on its left bank, presents the nearest approach to a complete section of the Potomac formation that I have been able to find. The Franconia Overlap rests upon the crystalline rocks at its western extremity, and is then seen overlying the James River Clays, the Rappahannock sands, and the Aquia Creek series in succession in passing eastward. The Mount Vernon series is well displayed on Pohick Creek and also in the White House Bluff. At this latter point the Basal Clays are seen at tide level and rise in places 5 or 6 feet in the bluff. They are overlain by the Rappahannock sand in its typical indurated state, and over this the Mount Vernon Clays and the Aquia Creek series are displayed in fine sections. It will be observed that the latest of the Tertiary deposits caps the White House Bluff, although it should not appear on the right bank of the Potomac at all. This is not the only case in which the Chesapeake has been found behaving like a superficial deposit and lapping over the beveled edges of older strata. Mr. Darton informs me that its dip is much less than that of the underlying beds. The green clays of the James River series are seen in the form of lenses and clay balls in the freestone. On account of the westward course of the Potomac at this point the width of the river is here about 5 miles, and when the bluffs at Fort Washington are reached the Iron Ore Clays are found at the base, overlain by a heavy bed, which must be referred to the Albirupean series, and over this both the marine Cretaceous and the marine Tertiary are distinctly seen. The section is about 12 miles long.

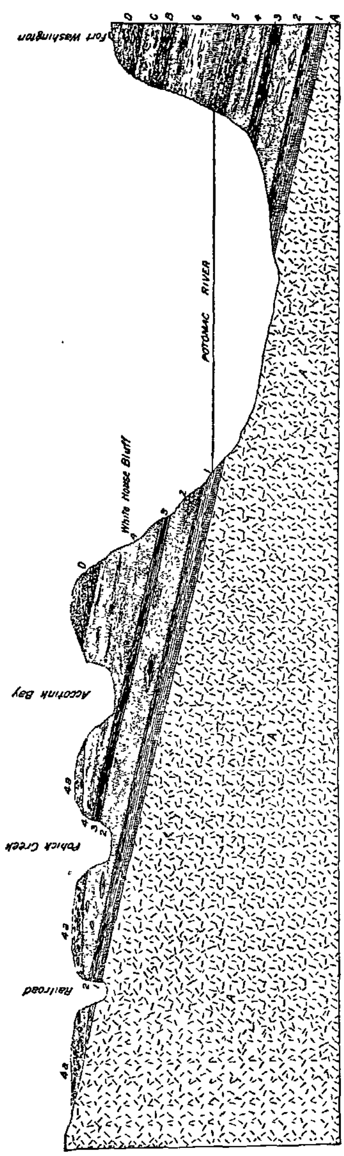


FIG. 5.—Section of the Potomac formation at White House Bluff and Fort Washington. 1. James River series. 2. Rappahannock series. 3. Mount Vernon series. 4. Aquia Creek series. 4*a*. Franconia Overlap. 5. Iron Ore series. 6. Albirupean series. A. Pre-Cretaceous (Cambrian slate and crystalline rocks). B. Marine Cretaceous (Severn). C. Eocene (Pamunkey). D. Miocene (Chesapeake).

PALEONTOLOGICAL RELATIONS.

The great neglect that the Potomac formation has suffered at the hands of geologists in the past has been chiefly due to the absence of fossil remains. The bulk of the literature relating to the geology of the Coastal Plain is devoted to descriptions of the marine deposits. In treatises of this character it is customary to make a brief mention of the existence of a belt on the west supposed to be of estuarine, fresh, or brackish water origin and destitute of fossils, and travelers crossing this belt, as did Sir Charles Lyell, dismiss the subject with the general remark that from its location it appears to belong to the Mesozoic age and to be either Wealden or Jurassic. The existence of vegetable remains is frequently alluded to, but no idea seems to have been entertained that these could have any value in determining the age of the beds. The few fossil shells that have been found are of brackish or fresh water types, and are of scarcely any importance from the geological point of view. The vertebrate remains are, so far as published, still more meager, but have much greater weight. A brief enumeration of what is known of the animal paleontology may fittingly precede the general discussion from the point of view of fossil plants.

ANIMAL REMAINS.

Invertebrates.—A collection of fossil shells was made many years ago by Professor Cope and turned over to Dr. Isaac Lea, who described them in the Proceedings of the Academy of Natural Sciences of Philadelphia in 1868.[1] They were more fully described and figured, with some additions, by Mr. Robert Whitfield in 1885.[2] These shells came from the banks of the Delaware River a few miles above Camden, N. J. In the same year Mr. T. A. Conrad described two species of Lamellibranchiate shells from the banks of the Raritan,[3] and Mr. Whitfield in the work above cited,[4] has added three others.

All the specimens from the Delaware River belong to the genus Unio, and Mr. Whitfield expresses no opinion as to their geological position. Those from the Raritan Valley belong to the genera Astarte, Corbicula, and Gnathodon, and to a new genus, Ambonicardia. Of these he says:

> All these forms found in the clays are estuary shells, and strongly indicate an estuary formation, which it undoubtedly is. * * * Gnathodon is known to occur in the Cretaceous, but I think not below. * * * Astarte is known in the Jurassic and possibly below, * * * while Corbicula certainly occurs in the Cretaceous and probably below. The new genus, which I have named Ambonicardia, is related to Homomya, and to the smooth forms of Pholadomya, but it will not answer for either. Consequently we get no help of sufficient value to establish the geological horizon of the beds from these molluscan remains, and aside from the evidence furnished by the plant remains we must rely entirely upon the stratigraphical position.[5]

He inclines, however, to the opinion that the beds are of Jurassic age.

Unio shells occur in considerable abundance in one of the typical localities of the Aquia Creek series, near Aquia Creek, where they were collected by my party in 1886. This is a small species, less than an inch in length, and occurs in immediate association with *Sapindopsis variabilis* and various other Aquia Creek species of fossil plants.[6] A specimen apparently of the same species, but somewhat larger, was collected by Mr. William Hunter on May 14, 1893, at the White House Bluff, in the light-colored clay above the Mount Vernon Clay, which is also referable to the Aquia Creek series. Another very similar specimen was collected by Mr. Gilbert Harris at Cockpit Point above the sandstone layer, and therefore probably also in the Aquia Creek series.

The only shell known to have been found at a lower horizon than the Aquia Creek series is a single specimen of the Unio collected by myself

---

[1] Vol. XX, pp. 162–164.

[2] Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey; Mon. U. S. Geol. Survey, Vol. IX, pp. 243–252, pls. xxxi–xxxv, Washington, 1885.

[3] Am. Jour. Conchology, Vol. IV, Philadelphia, 1868, p. 279.

[4] Mon. U. S. Geol. Survey, Vol. IX, pp. 22–28.

[5] Ibid., p. 23.

[6] Judging from a remark made by Professor Fontaine in a footnote on page 21 of his Flora of the Potomac Formation (Mon. U. S. Geol. Survey, Vol. XV), I conclude that it was specimens of this species that were submitted to Dr. C. A. White and referred by him to the Crustacean genus Estheria Mr. T. W. Stanton was unable to decide the question from any specimens in the collection that I was able to show him, but both he and Mr. Gilbert Harris expressed the opinion that they were probably immature Unios.

on May 29, 1893, in a bed belonging to the Rappahannock series and yielding abundant remains of *Sphenolepidium Sternbergianum*, *Athrotaxopsis tenuicaulis*, *A. expansa*, and other Older Potomac plants. This specimen is considerably smaller than any of those from the Aquia Creek series. The locality is known as Chinkapin Hollow and is about 2 miles northwest of Alexandria.

The paleontologists all admit that no important conclusions can be drawn from these invertebrate remains as to the age they represent. Their importance is of a negative kind in showing what the plants can not show, that the waters of the Potomac sea were certainly not marine in the paleontological acceptation of that term.

Vertebrates.—In 1859 a portion of a tooth of a saurian reptile found by Mr. Tyson in an iron-ore bed near Bladensburg, Md., was studied by Dr. Christopher Johnston, who proposed the name Astrodon for the animal to which it belonged.[1] This tooth was subsequently submitted to Dr. Joseph Leidy, who described it under the name *Astrodon Johnstoni* in 1864.[2]

Dr. Samuel Lockwood discovered a single dorsal vertebra of a saurian reptile in the clays which underlie the lower Greensand, or Clay Marl (Matawan), near the town of Matawan, Monmouth County, N. J., which was provisionally referred by Professor Cope in 1869 to the genus Plesiosaurus, and named for its discoverer *P. Lockwoodii.*[3] If this specimen was really found below the Clay Marl it must have occurred in the Amboy Clays, and may properly be included in the fauna of the Potomac formation, but of this there seems to be some doubt.

In December, 1887, Mr. J. B. Hatcher made a small collection of bones for Prof. O. C. Marsh from the bottom of an iron-ore pit some 2 miles southwest of Muirkirk, Md., which were described by Professor Marsh in 1888.[4] Five species are here described, all of them new to science, and all but two belonging to two new genera. At the conclusion of this paper Professor Marsh makes the following statement: "The fossils here described and others from the same horizon, seem to prove conclusively that the Potomac formation in its typical localities in Maryland is of Jurassic age and lacustrine origin." Professor Marsh informs me that he has recently obtained a much larger collection of bones from these and similar beds in Maryland, which he has not yet elaborated. It may be said with safety that all these vertebrate remains belong to the Basal Potomac; that is, either to the Rappahannock or the James River series, or both.

---

[1] Am. Jour. Dental Science, Philadelphia, new series, Vol. IX, July, 1859, p. 341.

[2] Cretaceous Reptiles of the United States; Smithsonian Contributions to Knowledge, No. 192, Vol. XIV, Article 6, May, 1865, p. 102.

[3] Synopsis of the Extinct Batrachia, Reptilia and Aves of North America; Trans. Am. Phil. Soc., new ser., Vol. XIV, Philadelphia, 1871 (see p. 40).

[4] Notice of a New Genus of Sauropoda and other New Dinosaurs from the Potomac Formation; Am. Jour. Sci., 3d ser., Vol. XXXV, No. 205, January, 1888, Appendix, pp. 89-94.

VEGETABLE REMAINS.

It is obvious from the foregoing that, so far, at least, as the correlation of the several members of the Potomac formation is concerned, the animal remains have no value, and it will be necessary to depend upon the fossil plants. Fortunately the flora of the formation is now so well known that it is possible to use it with excellent effect for this purpose. Indeed, without the flora it must be confessed that the subdivision of the Potomac formation would have been practically impossible, although with the aid of the plants it has been possible to show that the stratigraphical distinctions are by no means vague, and are in fact, for the most part, quite distinct. Paleontology, here as elsewhere, has its chief value in setting the limits to stratigraphical determination. Without it the similarity of lithological characters at widely different horizons is so great that it would lead to serious error, but with it these lithological similarities can be interpreted in their true light and such errors avoided. For example, it was natural to suppose, and was in fact supposed by some, that the white rocks at the mouth of the Patapsco and along that portion of the belt, almost the highest exposed, were the same as the Rappahannock freestone in Virginia, but when it is proved paleontologically that the former occupy a very much higher position, there is no difficulty in seeing that the rocks themselves differ widely in the two regions. So also it was natural that the colored clays at the extreme western margin of the formation should be confounded with those of the upper series, and this was very generally done until it was shown by the fossil remains that they must be of a very different character, as they are now clearly seen to be. Again, nothing could have been more reasonable than to have confounded, as was done before the flora was known, the light-colored sands and clays of the Aquia Creek series with those of the Rappahannock series; but now, when paleontology has proved their distinctness, the trained eye of the geologist can instantly recognize and differentiate these two series by their lithological characters alone. And so it is throughout.

The total number of distinct forms that have thus far been recorded as belonging to the Potomac formation proper, that is, east of the Mississippi River, is 737. The greater part of this flora is embodied in two important works: Professor Fontaine's Flora of the Potomac Formation,[1] and Dr. Newberry's Flora of the Amboy Clays, the manuscript and plates for which have recently been submitted for publication as a monograph of the U. S. Geological Survey. In addition to these, however, a number of papers by Dr. Hollick, chiefly relating to the Cretaceous flora of Staten Island and Long Island, have appeared, somewhat increasing the list.

It must not be supposed that this includes the entire present known flora of the Potomac formation. Immense collections have been made

[1] Mon. U. S. Geo. Survey, Vol. XV, 1889.

from a large number of localities in Maryland, Virginia, the District of Columbia, and Alabama which have not yet been elaborated. All that it has been possible to do was to go carefully through them and as far as possible to identify the forms already described in the works mentioned. Even this can not be thoroughly done until these collections are systematically worked up and the specimens drawn and described. But it could be approximately done without this, and no pains have been spared to render these identifications complete, because upon this depends to so large an extent the distribution of the flora among the numerous localities and the several horizons. Many of these identifications are necessarily provisional, and a final elaboration of this material may somewhat alter the general relations as they now stand. Such an elaboration will of course greatly increase the total number of forms, and it is not at all improbable that there have been collected at this date 1,000 species of Potomac plants.

As regards the significance of the Potomac flora as a whole, very little need be said beyond what is already known, viz, that the older forms, those for example that are exclusively confined to the James River and the Rappahannock series, represent an age as great, at least, as the lowest known Cretaceous, and indicate that, so far as comparisons can be made with other parts of the world, the Potomac formation began to be deposited either at the dawn of Cretaceous time or, more probably, a little before the close of the Jurassic age. The occurrence of a few rare and archaic dicotyledonous leaves even in the lowest James River beds would, in the light of all that is known of the origin of that type of plants, indicate that even these beds must come within the Cretaceous system. And yet, from the great abundance and high state of development of this type before the close of the Potomac period, and especially in the Middle Cretaceous—Dakota group of America and Cenomanian of Europe—no one would venture to assert that the subclass Dicotyledones had its absolute origin in the Cretaceous. Upon the whole, I am disposed to consider the Potomac formation as a Cretaceous deposit, but as occupying nearly the whole lower portion of that system; that is, as practically filling the interval from the close of the Jurassic to the base of the Upper Cretaceous, as that is commonly understood. The complete distribution of its fossil plants will, I doubt not, justify this conclusion.

Prior to the beginning of my investigation of this subject it was the common belief of geologists that the Raritan and Amboy Clays of New Jersey belonged to the Upper Cretaceous and were practically equivalent to the Dakota formation, although the earlier writers had generally referred them to the Wealden or Jurassic. The change of opinion on this question was brought about by the discovery of plant remains in the clay pits of New Jersey, a few of which were identified in 1878 by Professor Lesquereux with Dakota forms. This revised opinion was held by Dr. Newberry down to the time of his death, and was shared by me until 1892, when the evidence was so far in as to compel me to abandon it. Nevertheless, it is better known now than it was then that Dakota forms actually do occur in the Amboy Clays, but it must be supposed that these are such forms as have passed up from the Lower into the Upper Cretaceous. It is also true that a large number of Amboy Clay species are common to these beds and to all of the three Cretaceous deposits of Greenland—the Kome, Atane, and Patoot beds—and there is probably no doubt that the highest of these last belongs to the Upper Cretaceous. While the Atane beds have been referred, even on the authority of their animal remains, to the Cenomanian, there may still be a lingering doubt as to whether they may not be somewhat lower and the practical equivalent of those of New Jersey. The Greenland deposits would thus seem to be a simple extension of the Lower Cretaceous of the Atlantic border.

It can not be denied that a great difference exists between the floras of the Lower and Upper Potomac as thus defined, and the evidence of their unity rests upon the stratigraphy, as showing a general continuity of deposition. The chief difficulty in the way of subdividing this admittedly prolonged epoch is the impossibility of finding any hard and fast lines; and singularly enough, this difficulty is greatest just where it ought to be least, viz, between the Aquia Creek and the Albirupean series, and especially between the Iron Ore series and the beds above. The great geologic break, as already stated, occurs at the close of the Rappahannock series. The existence of the Iron Ore Clays above the Aquia Creek series, and without any decided evidence of erosion, would seem to furnish a sufficiently long period for the really great change that took place in the flora and separates that of the Aquia Creek series from the great dicotyledonous flora of the Raritan and Amboy Clays.

More clearly to express the chronological relations of the several series, I shall designate the James River and Rappahannock series, taken together, as the Basal Potomac, and the four lowest members, viz, the Basal Potomac and the Mount Vernon and Aquia Creek series, taken together, as the Older Potomac. All above the Aquia Creek series may then be treated as the Newer Potomac. The Aquia Creek flora, separated as it is by the great break from the Basal Potomac, and by the nonfossiliferous Iron Ore Clays from the Newer Potomac, may, in harmony with this classification, be called the Middle Potomac.

With these preliminary remarks I shall now proceed to consider the several floras of the Potomac formation, beginning with the lowest, and to discuss their interrelations.

THE JAMES RIVER FLORA.

In treating of the stratigraphical relations of the James River and Rappahannock series it was made sufficiently clear that they constitute practically one prolonged series of deposition, but that the basal portion is usually more argillaceous and often consists entirely of clay, while the upper portion is almost exclusively sand and gravel, with clay inclusions, the latter sometimes quite extensive and holding the plants, while the arenaceous part is often solidified into rock. It was also shown that at the base of the freestone, or of the sand when not lithified, there usually occurs a lignite bed, the lignite being deposited in clay, and this carbonaceous clay alternates with the sand toward the base of this series, so that there may be sand, and especially gravel, consisting chiefly of rounded vein-quartz, below some or all of the lignite beds. For these reasons this lignite layer was assigned to the Rappahannock series, but in many places this is wanting and, as on the western shore of the Potomac north of Aquia Creek, the freestone rests directly upon heavy clay beds, which are not carbonaceous, have a greenish color, and contain no vegetable remains. There are indications at some places that even these nonfossiliferous clays are underlain by sandy deposits, often ferruginous, and differing essentially from anything else in the formation. Such indications are to be found below Cockpit Point on the Potomac River, and beds of this kind crop out at the surface some miles west along the north and south roads, where they are clearly overlain by the purple clays, which have this color solely through weathering.

It must not, however, be inferred that the distinction between the James River and Rappahannock series is purely stratigraphical. There is an obvious change, though a gradual one, in the character of the flora from the base upward. Even in the case of the common species, occurring in both series and sometimes passing up into the Aquia Creek series, there is either an increase or diminution in their abundance. Such species as *Dioonites Buchianus* (Ett.), Born., and its varieties are extremely abundant in the lower deposit and grow more rare in ascending, while many of the typical Rappahannock species also occur in the James River series, but only rarely; and in general the distinction in the flora of the two may be said to be quantitative rather than qualitative.

The James River series has yielded 152 species of plants, or nearly 21 per cent of the total known flora of the Potomac formation. Of these, 69, or 45 per cent, are confined exclusively to that series, while 73, or over 48 per cent, are common to the James River and Rappahannock series. Of these last, 44, or nearly 29 per cent, are confined to these two series. The remainder of those that are common to the two are found at higher horizons.

THE RAPPAHANNOCK FLORA.

The number of forms described from the Rappahannock series is 221, or 30 per cent of the known flora of the Potomac. This is by far the richest of all the floras of the Older Potomac, but, as has been shown, the thickness of the beds is much greater than that of either the James River or the Aquia Creek series. As already remarked, the preponderance of the plants thus far described were found at one very restricted locality in the city of Fredericksburg, but now a large number of other plant-yielding beds are known, and many specimens have been collected which have not yet been adequately determined. With the exception of a considerable collection from thin clay shales between heavy sandstone layers of the typical freestone at Cockpit Point, all the other collections mentioned are from the lignite beds below the sand. Among the localities of this class, besides the two situated on Potomac Run, treated by Professor Fontaine in his Flora of the Potomac Formation,[1] there may be mentioned two other very promising ones more recently discovered by myself and by no means exhausted as yet. One of these is known as Chinkapin Hollow, and is situated about half a mile east of Fairfax Theological Seminary, and some 2 miles northwest of Alexandria near the Leesburg pike. The other is at the new reservoir in the city of Washington. The plants occur in the bed of the excavation, most of them on the east side, nearly opposite the shaft. A few were found, of quite different types, in a very light brown clay close by the shaft on the west side, and immediately below the position of the huge petrified log of *Cupressinoxylon McGeei*, described by Professor Knowlton.[2]

Of the 221 Rappahannock species, 120, or over 54 per cent, are exclusively confined to that series; 44, or nearly 20 per cent, are common to it and the James River series and have no further distribution; 73, or over 33 per cent, are common to the Rappahannock and James River series, 25 of which, or over 12 per cent, are found at higher horizons.

THE MOUNT VERNON FLORA.

Only 42 distinct forms from this horizon have as yet been given names, which is less than 6 per cent of the entire Potomac flora; but the collections already made contain a considerable number of new species, some of them very well preserved, whose affinities have not yet been satisfactorily made out. These collections have been the result of three different visits to the localities at Mount Vernon and White House Bluff, in all of which both the time for collecting and the facilities for transporting the fossils were greatly limited and we were obliged to abandon the work at the point where it seemed to have become the most interesting. Notwithstanding the uncertainty that attends all collecting in the clays of the Potomac formation, I can not help feeling that the possibilities are still very great, if not practically unlimited, at these localities.

In considering the relations of this flora to the others it will be profitable to deal with some of the species separately. Lying as the beds do directly intermediate between the Rappahannock and Aquia Creek series, it is important to note what plants are found below and what

[1] Mon. U. S. Geol. Survey, Vol. XV, 1889, pp. 17–18.
[2] Bull. U. S. Geol. Survey No. 56, 1889, p. 46, pl. ii, fig. 5; pl. iii, figs. 1–5.

ones above, as well as those that occur both below and above. To the first class, viz, those found only at a lower horizon, belong *Zamites tenuinervis* Font., which is found in both the James River and the Rappahannock series, and also occurs in the flora of the Trinity division, in Texas, and *Z. crassinervis* Font., otherwise confined to the Rappahannock; also *Cladophlebis rotundata* Font., confined to the Rappahannock, and *Thyrsopteris brevifolia* Font., confined to the James River series. There is also the dicotyledonous leaf, *Ficophyllum tenuinerve* Font., hitherto confined to the Rappahannock series. Of the second class, viz, not found below but occurring in the Aquia Creek series, we have *Baieropsis denticulata angustifolia* Font., and two dicotyledonous leaves, viz, *Menispermites virginiensis* Font., and *Proteæphyllum reniforme* Font. Of those that pass up from the Older Potomac into the Aquia Creek series there is the widely distributed *Thyrsopteris rarinervis* Font., which also occurs in both the Trinity and Shasta group, *T. decurrens* Font., and *T. bella* Font., *Sphenopteris latiloba* Font., and *Cladophlebis constricta* Font., which are also Kootanie species, *Nageiopsis longifolia* Font., common also to the Shasta group, and *Sphenolepidium Sternbergianum* (Dunk.) Heer; while of dicotyledons we have *Myrica brookensis* Font., and *Rogersia angustifolia* Font. There are a few forms which are believed to be identical with Amboy Clay species. One of these is *Sphenopteris grevillioides* Heer, found only by Mr. White at Gay Head, but so near to the form referred by Newberry to *Asplenium Foersteri* Deb. and Ett., that it may be necessary to unite them. There is also a cycadean leaf which seems to be *Podozamites marginatus* Heer. One of the forms of Celastrophyllum is very closely related to, if not identical with, *C. Brittonianum* Hollick, from the Amboy Clays.

These enumerations are sufficient to show the intermediate character of this flora. But what gives it its chief interest is the occurrence of a number of entirely distinct forms not hitherto found in any part of the Potomac formation. Some of these I have thought it worth while to illustrate in this paper.

On Pl. II, Figs. 1, 1*a*, 2, 3, is shown a delicate little fern which undoubtedly belongs to the genus Scleropteris. I am satisfied from intermediate forms that all these figures belong to the same species. Fig. 1*a* represents the small fragment, Fig. 1, magnified three diameters. A comparison of these forms with *Scleropteris tenuisecta* Sap.,[1] from the Upper Jurassic (Kimmeridgian) of France, shows a very close resemblance, but the European form is often much more branched and larger. But for the considerable difference of age and the wide geographic separation the American form might perhaps be regarded as only a variety, but under the circumstances it seems better to treat it as a distinct species. I have therefore decided to name it *S. vernonensis*.

The specimens figured on Pl. II, Fig. 6, were on one large slab, as

[1] Plantes Jurassiques, Vol. IV, pl. liv, figs. 2-4; pl. lv, figs. 6, 7; pl. lx, fig. 5; pl. lxi.

they appear in the figure. The leaf is clearly cycadaceous, and resembles many of the specimens that have been referred to *Zamites tenuinervis* Font., where the base is not shown. In the present case the absolute base is not preserved, but the narrowing which takes place immediately above the base would seem to indicate that it reached the rachis in a point. It does not therefore agree with the characters of Zamites, but neither does it agree with those of Podozamites. The fruit which occupies the lower right-hand corner bears a very strong resemblance to that of some species of Zamia. It is about the same size and form as the immature fruits of *Zamia integrifolia* Willd., collected by Mrs. Ward and myself at Dunnellon, Fla., in April, 1891, which I caused to be figured for the Century Dictionary under the word *Zamia*. The specimen is preserved in alcohol, and I have carefully compared it with the fossil. Some of the leaves of Zamia proceed from a point, and there is nothing in the present leaf that is opposed to its reference to that genus. The presumption is strong that the leaf belongs to the same plant as the cone. I know of nothing in the fossil state with which it can be identified, and the leaf does not agree with that of the living species with which I have compared the cone. I am therefore obliged to regard it as a new species, and will name it *Zamia Washingtoniana*, thus dedicating it to Washington, whose tomb is so near the spot where the plant flourished.[1]

The specimen figured on Pl. III, Fig. 2, is of unusual interest. It occurs on the same slab with the plant last described, and also with the one represented in Fig. 4 of Pl. III. The impression on the slab is clear, and reminds one at first sight of certain herbaceous forms with sheathing joints, as, for example, Lychnis and the rush-like Fuirena and Dulichium. The specimen shows three of these joints, in the lowermost of which the sheath has fallen away. In the middle joint the sheath is clearly preserved, causing an enlargement of the node, apparently consisting of a single piece, and having a crown of distinct teeth at the summit. Four of these are visible upon the face that is presented in the impression. From beneath this sheath, at its summit, there are clear indications of two protruding objects, differing somewhat in form, but both of which may have been the bases of branches which had borne flowers. The third node has the sheath still better preserved, which enlarges upward and is crowned by a row of teeth, of which six are visible in the impression. From beneath this sheath three flattened scales similar to one of those at the next sheath below are distinctly seen. These give at first the impression of an inner sheath emerging from beneath the outer one, but it seems more probable that they are also the bases of branches. This view is strengthened by the occurrence of what looks like an inflorescence on the opposite side of the

[1] The distance is less than a mile. It is also worth noting that Washington's tomb stands on the slope at about the top of the Rappahannock freestone. Very likely it may have been purposely so located in order to secure a basis on solid rock. If this is the case the excavation must have been made in the Mount Vernon Clays, which always occupy that position.

stem at about the same level as the summit of these scales, as if borne upon one of these branches that emerged from the side of the stem opposite the beholder. A little above this, on the left, is seen an elongated body which may have proceeded from the same sheath. Still higher up on the left and from what would appear to be the center of an internode, but which is probably a true node from which the sheath has entirely disappeared, there proceeds a short, scaly stem bearing a large and distinct ament or immature fruit, the basal portion of which is covered with scales and the terminal part of which seems to consist, so far as can be seen, of larger enveloping scales inclosing the flowers. These are much longer than the lower ones, and terminate in an acute point which is sometimes bent inward at the tip, the body of the scale being partially reflexed. Assuming this to proceed from a node, the next internode above is shorter than the one below, but the expansion of the stem at the node is clearly perceptible, and several of the scales of the sheath are preserved. From this node there appear to have proceeded several flowering branches, remains of three of which are shown in the specimen. The one on the right has disappeared, except the base of the stem showing the mode of insertion. On the left, however, we have another well-preserved ament similar to the one below, but somewhat smaller and apparently less mature. From what can be seen of the scales on the lower portion, they appear to have been slightly reflexed or squarrose. The terminal ones have the same character as those of the next lower ament, but are better preserved, and the tips of nearly all of them are distinctly bent backward. Immediately above this ament there are the remains of another one, of which only the terminal scales are preserved. Some other imperfect bodies can be seen at the same level on the right of the stem, which may be the remains of still another ament.

The whole plant shows distinct longitudinal ribs with intermediate grooves, and the elevated portions are seen to pass into the scales of the sheaths, which are probably consolidated into a single piece, at least below.

In endeavoring to determine the type of vegetation to which these several characters most clearly point, great difficulties have been encountered. I have shown both the specimen and the drawing to a number of well-known botanists, and especially to Mr. Frederick V. Coville, botanist of the Department of Agriculture, who accompanied me on several of my expeditions to the Mount Vernon beds. It was he who first suggested the possible relation of this plant to Casuarina, and we have together compared it with all the living forms in the National Herbarium.

I have also carefully examined all the fossil species that have been figured, including *C. Sotzkiana* (Ung.) Ett., which Unger referred to Ephedrites, as related to Ephedra. Ettingshausen reexamined the material and found small branches bearing the characteristic nodes and scales of Casuarina, and it has since been generally referred to that genus. I find no cases in which stems as large as those of the plant under discussion bear such scales, but in some species, as *C. glauca* Sieber and *C. torulosa* Ait., such branches are much larger than those of *C. equisetifolia* Forst. Moreover, the male inflorescence of Casuarina is terminal, or forms a terminal spike or ament; but in some species, as *C. quadrivalvis* Labill., this terminal spike becomes elongated, revealing its true nature as consisting of a series of nodes with imbricated sheaths, from underneath which the male flowers, reduced to mere stamens, project. I have represented this in Fig. 4 of Pl. III, from a specimen in the National Herbarium from Tasmania. Fig. 4*a*, enlarged two diameters, brings it to about the dimensions of the fossil plant.

Except, however, that in Ephedra the scales are wanting, the resemblance is much greater to some species of that genus, and the male plants of *Ephedra monostachya* L. (*E. vulgaris* Rich.) or *E. fragilis* Desf., as figured by Göppert in his Bernstein Flora (pl. iv, fig. 11) and by Unger in his Flora of Sotzka (pl. v, fig. *a*), bear a striking resemblance to it.

I have not overlooked a certain superficial resemblance which this fossil bears in the character of the joints and sheaths, as well as in the striation of the stem, to the living genus Frenela, and especially to Schenk's fossil genus Frenelopsis. Our American species of Frenelopsis, as described by Fontaine, lack these characters almost entirely, at least so far as the specimens show, but some of the figures of the smaller branches of *F. Hoheneggeri* (Ett.) Schenk, figured by Schenk, approach it more closely, though the organs that proceed from beneath the scales are always lesser branches and not flower bearing, and the inflorescence in general is wholly different. Saporta's extinct genus Philibertia, formerly supposed to belong to Frenelites, and some of the branches of which he had referred to Equisetum, seems to have a still closer resemblance to the Mount Vernon plant. Saporta unites with it the *Casuarina Haidingeri* of Ettingshausen, at least in part, and the latter's figures (Tert. Fl. Häring, pl. ix, figs. 17, 18), though much smaller, show when enlarged (fig. β) a marked approach to our plant, while some of Saporta's figures of Philibertia (Ann. Sci. Nat., 7ᵉ sér., Bot., Vol. VII, 1888, pl. iii, figs. 6*a*, 6*b*, 7, 7*a*) have the stems, joints, and sheathing scales more nearly like those of the Potomac form than any others that I have been able to find. Still, from consideration of the reproductive parts and the general description given by Saporta it is impossible to believe that it belongs to that genus.

Returning to our comparisons with Casuarina, it is evident that the fossil plant, notwithstanding the close resemblance in the stem and sheaths, can not be the exact homologue of the male plant of that genus. As already remarked, the staminate aments are always terminal. In our plant the flowers are obviously borne on short stems which proceed from the nodes. The inflorescence described is therefore clearly in the nature of an ament. Each of these would thus represent, homologically, the entire male ament of most species of Casuarina, even the elongated one of *C. quadrivalvis*, of which Figs. 4 and 4*a* show only a few of the lower nodes. Above these the nodes become contracted, the internodes disappearing entirely and the inflorescence taking the form of an elongated spike or catkin. If, however, we turn now to the female inflorescence we find a somewhat different state of things. Here in most species no distinct sheath is found on the principal stems, but these are jointed and ribbed, and the ribs are terminated at the nodes by a crown of scales imitating sheaths. From the axis of these principal nodes, or apparently from beneath the sheaths, there proceed short flower-bearing branches, provided with close scales, ovate in shape. At the summits of these short branches the fertile aments are borne in the form of more or less spherical heads or cones. These are also covered with scales similar to those on the stem, the upper ones being more elongated, sharp pointed, and reflexed. In their maturer stages these latter scales very closely resemble those of the fossil. Fig. 3 shows four of these nodes, two of them giving off flower-bearing branches, drawn from a specimen of Casuarina found in the National Herbarium, upon the label to which it is said to have been cultivated in Italy, to have belonged to the herbarium of J. T. Moggridge, and to have been received from Kew in 1880; but no specific name is given to the specimen. If this figure be compared in detail with that of the fossil plant it will be admitted that there are many striking resemblances, the chief difference being the absence of a manifest sheath at the nodes of the living plant. Now, it may be supposed that the general type of structure of all the parts of Casuarina was originally the same, and that primarily each node should be provided with a sheath, as is the case in the small ultimate branches of the male plants as seen in Figs. 4 and 4*a*. If we can imagine a species in which such sheaths are present on the larger branches of the female plants no essential difference would exist between such a species and the fossil species under consideration, and it is altogether probable from the nature of the inflorescence of the fossil plant that it belongs to a fertile branch, and that the aments are female, corresponding to those of Fig. 3.

I have therefore decided upon the whole to refer this form to Casuarina, with all necessary reservation, and to name it, in honor of Mr. Coville, *C. Covillei.* It would certainly be an interesting fact if it were proved that this anomalous type of vegetation lived in America during Lower Cretaceous time. It is in the Potomac formation that the absolutely oldest dicotyledons known have been found. The genus Casuarina has recently been subjected by Treub[1] to a searching investigation, and he decides that it can not properly be placed among the dicotyledons, as has heretofore been done; also that it can not be

[1]Sur les Casuarinées et leur place dans le système naturel; Ann. du Jardin botan. de Buitenzorg, Vol. X, 2^{me} partie, 1891.

regarded as monocotyledonous, while at the same time it is clearly angiospermous. He therefore gives to this sole genus a rank coordinate with that of the combined monocotyledons and dicotyledons, the Chalazogams, all other angiosperms constituting the Porogams. If Treub's conclusions are sustained the genus Casuarina must be regarded as the least-developed angiosperm, and therefore the plant which is most nearly related to the Gymnosperms. As the Gnetaceæ, to which Ephedra belongs, rank highest among the Gymnosperms, the effect of this is to bring the two genera, Ephedra and Casuarina, as near together systematically as they have always seemed to be from their superficial aspect.

Fig. 5 of Pl. III represents a form which must be referred to the genus Sagittaria. All of the leaf except the upper portion is well preserved, although on both sides of the specimen, from a short distance above the base, the margins are rolled under and hidden from view. This is clearly seen in the specimen, and the nerves on the right may be traced some distance around this margin. Unfortunately, the finer nervation is not visible. I have had figured and placed in immediate juxtaposition (Fig. 6) a small leaf of *Sagittaria latifolia* Willd., now growing in the vicinity of Washington. The long, pointed auricles of the latter are represented in the fossil form by short, rounded ones, but all of the principal nerves are the same in both, and may be traced the greater part of their length in the fossil specimen. The two chief lateral nerves probably followed the margin above the middle, as in the living species, but the inflection of the margin makes them appear to terminate below the summit.

I have named this species *S. Victor-Masoni* for Mr. Victor Mason, who has accompanied me in nearly all my expeditions to this part of the Potomac formation, and has actively assisted in making the collections. This leaf was found at the locality in the White House Bluff described above.

The singular object depicted on Pl. III, Fig. 7, though a very definite impression, has nevertheless caused much research, and it still remains very doubtful what manner of plant it represents. Besides the specimen figured, several other less perfect ones occur in the collection, all presenting substantially the same general aspect. The first impression one gains from a casual view of the specimens is that of a large flower, such for example as that of an Iris, or flower-de-luce, and for a long time I had treated it under that name, but when it came to a matter of delineation and very careful study; and especially of comparison with flowers of the living *Iris versicolor* L., most of the resemblances vanished, and it even became doubtful whether it represents a flower at all and not rather the open valves of some dehiscent pod, such as those of the lily family. While only five such valves can be seen, there is room to suppose that a sixth lies concealed behind the other parts. But if there were originally only five it will have to be referred to some of the dicotyledonous orders. If it represents a flower the same would be true, but it would be necessary to suppose that the petals were of a leathery consistency and were either corrugated laterally along both sides of the median line or else that this corrugation results from the unequal contraction of the relatively thin outer and the very thick keeled central parts. But it is almost possible to distinguish two rows of small granular bodies, arranged along the median line and at right angles to it, which might represent the seeds of a capsule, although the arrangement is quite unusual. It can not be ascertained with certainty whether the several parts are really distinct and somewhat imbricated or whether they may not be united at different distances from the base. The longitudinal striæ, proceeding from the base of each part, are very distinct in the two upper members, but lose themselves before reaching the middle. The peduncle can be seen, as shown in the figure, but it is doubtful whether we here have a view of the lower (outer) or of the upper (inner) portion. Whatever may be true of the three lower lobes, it seems quite certain that we are viewing the inside of the two upper ones. A more exhaustive comparison with a large number of flowers of living plants, and with various capsules and pods, may yet reveal the true affinities of this interesting plant. But time is lacking at present for such researches, and I am compelled to follow the example of most paleobotanists who have discovered floral organs, and to refer it to some one of the comprehensive genera which have been created for the reception of such forms. Even here I seem obliged to decide the question as to whether it is a flower or a fruit, which, as has been seen, can not be done. Upon the whole I can not perhaps do better than to place it in the genus Antholithus. In the specific name, *Gaudium-Rosæ*, I design to commemorate the fact already mentioned that the summit of the bluff immediately over this plant bed was the spot known as Rose's Delight, referring to a member of the Fairfax family who specially delighted in this prospect.

In making collections from the Mount Vernon Clays the forms that first and most forcibly strike the eye are the little leaves of Populus, which are so common in them. The exceedingly definite and perfect character of these impressions leads one at first sight to think of a quite recent formation. The form and outline are strikingly distinct, and the nervation is as clear as the nature of the matrix will allow. But upon comparison with the leaves of living species of Populus, and, indeed, with those from any of the more recent formations, it becomes obvious at once that we here have to do with an altogether distinct type of the genus. In fact, there may be grave doubts as to whether these forms really belong to Populus, and I have taken some trouble to examine a number of other genera, such as Grewia, Paliurus, etc., to see whether they do not more nearly conform to those types. Saporta and Marion have expressed doubts with regard to a number of the

Arctic forms of Populus figured by Heer.[1] But in these they would rather see a resemblance to Cocculus. No such resemblance can be seen in the forms before us, and until further light can be shed upon the problem I shall be obliged to keep them within the genus Populus, to which prima facie they so obviously belong.

The specimens figured on Pl. IV, Figs. 1–4, represent at least two distinct species. I had been disposed to regard the form represented by Fig. 3 as distinct from that represented by Figs. 1 and 2. The serration of the margin is much shallower and the difference seems more marked in the specimens than in the figure. The basal sinus differs slightly, and there is a still greater difference near the apex, which is slightly constricted in Figs. 1 and 2 and not at all in Fig. 3. The nervation of all may be said to be identical, except that it is more slender in Fig. 3, and the midrib especially is much thinner. As the petiole is entirely wanting no comparison of this can be made. The two specimens, Figs. 1 and 2, undoubtedly represent the same form, and the smaller one appears to be somewhat less mature. As this is the first true Populus that has been found in the Older Potomac I have named it *P. potomacensis*.

The other form, Fig. 4, though similar in all other respects to the ones last described, is not only much larger and longer in proportion to its width, but it has a deep acute basal sinus, causing the base to present two distinct auricles, from which circumstance it may be called *P. auriculata*. I am aware that the immature leaves of Populus, and those borne on small shoots at the base of trees and on seedlings, are often much more elongate than the normal type of leaf of the same species, and if this form were diminutive, or bore any evidence of being immature, it might be grouped with the others; but as it is a larger form, and has every appearance of being fully developed, it is neessary to consider it as specifically distinct.

The genus Populus has played a most interesting rôle in the geological history of plants. It is one of the most widespread genera of fossil plants, and the forms which its leaves present are exceedingly variable. It would seem that there must have been several distinct lines along which it has developed. All the species of Populus now living have what may be called a pinnate nervation, that is, it consists mainly of a prominent midrib, from which proceed a greater or less number of secondary nerves. Sometimes there is a pair near the base which are considerably stronger than the rest, but they rarely or never obtain such prominence as to be regarded as primary nerves. Moreover, their general direction is nearly straight, whatever the angle may be, and they do not tend to curve inward toward the midrib in ascending. The late Tertiary types from European beds, for example from Œningen and from the Upper Rhone, conform in the main to this nervation.

[1] Recherches sur les Végétaux Fossiles de Meximieux; Archives du Muséum d'Histoire Naturelle de Lyon, Vol. I, 1876, pp. 264–265.

The Arctic Tertiary types, on the contrary, present a distinct style of nervation. They come within the class which is called palmately nerved leaves—that is, the two nerves that proceed from the summit of the petiole have that degree of prominence which entitles them to be called primary nerves. A special peculiarity of most of these leaves of Populus is that these lateral primaries, instead of proceeding at a given angle more or less directly to the margin, almost immediately begin to curve upward, and ultimately curve inward, the upper extremity sometimes nearly returning to the midrib at the apex, a type of nervation which, when complete, is called acrodrome. Now it is found that the American fossil species of Populus, with a few exceptions, have this latter type of nervation, especially those belonging to the Fort Union group, from which such large numbers have been collected.

The plants that are here under consideration seem to be almost an exaggeration of the type described, which may be called the American type of nervation. But the great peculiarity of our Mount Vernon forms of Populus is their remarkably distinct cordate base. We may suppose that this line of the genus had its origin in America near the base of the Cretaceous, and that it has for its immediate descendants all the more recent American forms that have been found. Our Fort Union group seems to be substantially the same as what has been called the Upper Laramie in western Canada, which the Canadian geologists have succeeded in connecting with the Mackenzie River beds, that have yielded a similar flora, and these in turn would appear to be practically the same as nearly or quite all of the Arctic Tertiary beds, whose flora does not widely differ from it. The genus Populus is found throughout these Arctic beds, and the two species, *P. arctica* Heer and *P. Zaddachi* Heer, found on the north side of Grinnell Land, in latitude 81° 46′ N., give to this genus the distinction of having attained the "farthest north."

For a long time Heer's *Populus primæva* from the Kome beds, was quoted as the most ancient dicotyledonous plant. We have in the Potomac formation, even in the James River series, a considerable number of dicotyledons, some of which are probably related to Populus; but these beds are much older than the Kome beds. If there were any way of correlating the Mount Vernon beds with the Kome beds it would probably be found that they are of nearly the same age. But the forms of Populus from the Mount Vernon Clays are widely different from that of *P. primæva*, which does not possess the American type of nervation.

Taking all these facts into consideration, it will probably be admitted that the genus Populus, historically considered, is the most interesting of all dicotyledonous genera.

The only other one of the numerous forms which can not be identified with anything heretofore described, which I have selected to represent the general character of the Mount Vernon flora, is a delicate, elongated dicotyledonous leaf (Pl. IV, Fig. 9), nearly lanceolate in form and regularly and finely toothed around its entire border, and which is clearly referable to the comprehensive genus Celastrophyllum, so characteristic of the Potomac formation. But this species differs from all others in several important respects. In the first place, the angle which the secondary nerves make with the midrib is very much less than that of any other species, and gives the plants a considerable resemblance to the pinnules of certain ferns, as, for example, Zamiopsis (compare *Z. longipennis* Font., Flora of the Potomac Formation, pl. lxi, fig. 8). This resemblance is still further heightened by the forking of these nerves, but a close comparison of such dichotomy shows that above the forks the two branches converge somewhat and proceed in a rather irregular manner to the margin. These and other characters, as well as the general aspect, show that our plant can not be a fern, but must be a dicotyledon, and certainly comes within the limits of the genus Celastrophyllum. Two specimens have been collected from the White House Bluff, and in both cases the counterparts are preserved, but in neither have we the entire base of the leaf, so that there is some doubt as to its form. It approaches *C. Brittonianum* Hollick of the Amboy Clays, but there is another form from the Mount Vernon Clays which, from the specimens thus far collected, I am obliged to refer to *C. Brittonianum*, and in this the nervation is quite different. The present form is clearly a new species, and I have named it *C. Hunteri*, for Mr. William Hunter, who accompanied the expedition on which these plants were collected, and to whom, from his lifelong residence in this district, I am indebted for many historical facts in connection with the localities.

In addition to the above-named new species there are a few others of such special importance that I have included them with the illustrations herewith furnished.

On Pl. II, Fig. 4, is represented the pinna of a small fern from the Mount Vernon bed, in which the fruit dots are distinctly shown. In the enlarged figure (4*a*), magnified five diameters, these are seen to be very nearly circular in shape, but in a few cases they are slightly reniform. The plant therefore undoubtedly belongs to the genus Aspidium, but does not exactly agree with any of the published figures. It probably comes nearest to *A. virginicum* Font., and Professor Fontaine, who has seen both the specimen and the figure, is disposed to refer it to that species, which is pinnatifid and of which our plant represents one of the intermediate pinnæ.

On Pl. II, Fig. 5, is shown the best developed of a series of specimens of another fern, which I was at first disposed to refer to *Asplenium Foersteri* Deb. and Ett., from the Aachen beds, Upper Cretaceous (Denkschr. Wien. Akad., Vol. XVII, 1859, pl. ii, figs. 4–7). The resemblance is quite close to fig. 4 of those authors, which seems to represent a defective specimen, but it differs materially from the much better specimen represented in fig. 7. Nevertheless, Dr. Hollick, who is familiar with the forms found by Dr. Newberry in the Amboy Clays and referred to that species, was of the opinion that the Mount Vernon plants were the same as those of the Raritan, and this may, in fact, be the case. I am, however, more inclined to think that our plant is a form of *Sphenopteris grevillioides* of Heer (Fl. Foss. Arct., Vol. III, pt. 2, pl. xi, figs. 10, 11), and in this Professor Fontaine agrees with me. Mr. David White identified one of the Gay Head specimens with this species (Am. Jour. Sci., 3d ser., Vol. XXXIX, pl. ii, fig. 1). This seems to be somewhat different from Dr. Newberry's specimens, and also from those of the Mount Vernon Clays, but that all of these forms constitute a general group extending from the Older Potomac into the highest beds of the Newer Potomac there seems to be no doubt.

The fine fruiting, coniferous plant represented in Fig. 1 of Pl. III is of very special interest. When first found I supposed it to be a Sequoia, and indeed it has some slight resemblance to forms of *S. fastigiata* Heer from the Cretaceous of Greenland; still, it is clearly not that plant, and the foliage does not agree with that of any species of Sequoia. In the same bed I found undoubted specimens of *Glyptostrobus brookensis* Font., with male aments attached, but neither the scaly branches nor the cones of the specimen under consideration conform to that genus. It is only in the genus Sphenolepidium that we find identical foliage, and that of *S. Sternbergianum* (Dunk.) Heer, as shown by numerous specimens from the Basal Potomac, agrees in this respect so exactly that but for the fruit there would have been no hesitation in referring this plant to that species. Unfortunately no fruiting specimens of *S. Sternbergianum* have been found in America, and those figured by Schenk from the Wealden of Europe possessed somewhat elongated cones, thus differing from those of our plant. In the midst of these difficulties I sent the drawing to Professor Fontaine, whose remarks upon it are as follows:

> This, I think, is certainly *Sphenolepidium Sternbergianum.* The cones have the scale closed, and in this condition do not look like the same when the cones are dissected by the opening of the scales and their partial removal. This latter is the case with the cones of my *S. virginicum,* and in Schenk's figs. 10–13, pl. xvii (Fl. d. Nordwestdeutsch. Wealdenformation) of *S. Sternbergianum.* Your cones are, as you suggest, probably immature, and I think somewhat distorted by pressure. Their immaturity will account for their small size, and the closure of the scales for the difference in appearance from Schenk's cones.

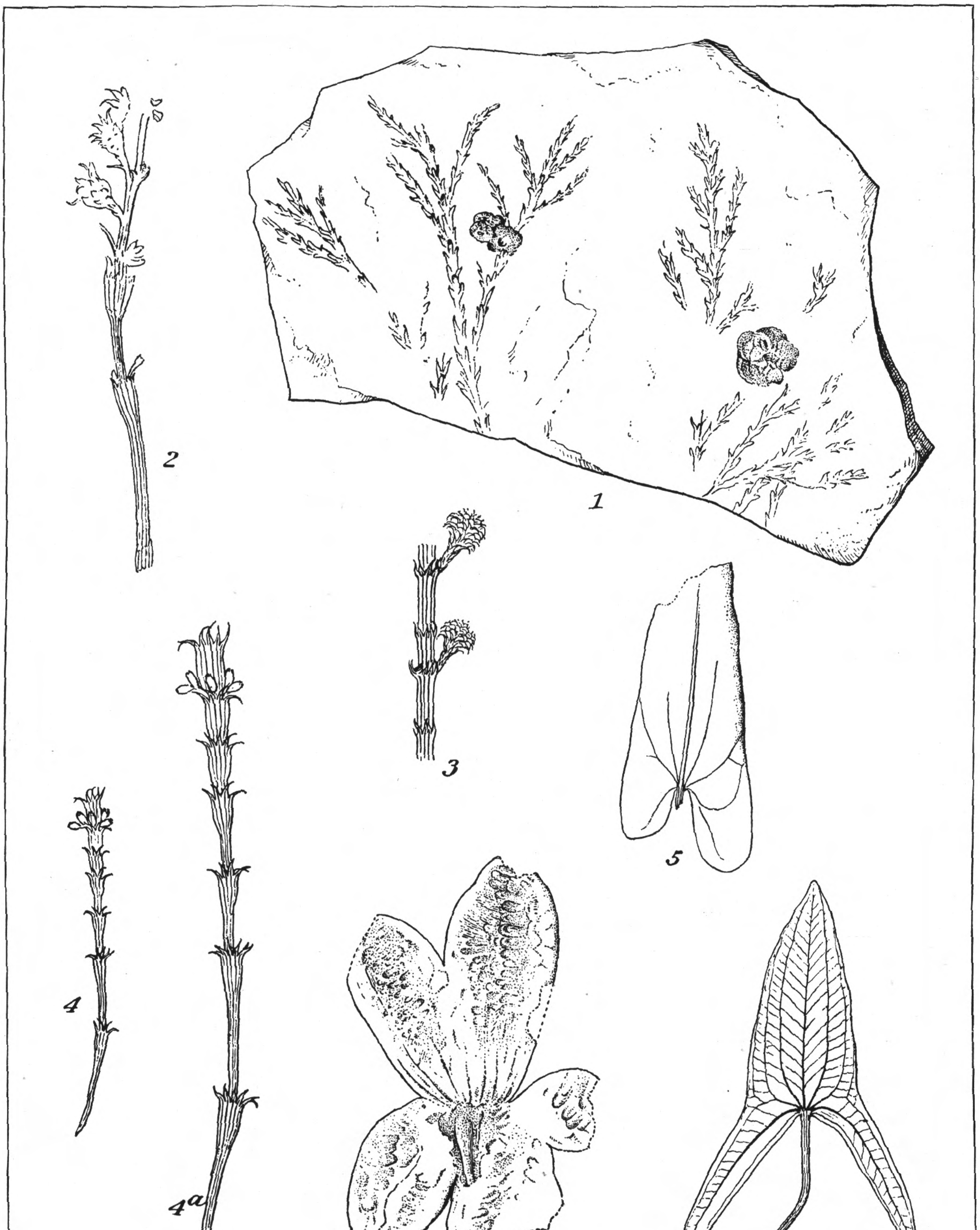
I accept Professor Fontaine's conclusion, and with this discovery of the fruit of this species we have a very complete representation of one of the most common trees of Older Potomac time. In his Flora of the Potomac Formation, Professor Fontaine had figured a large number of "male aments" (pl. xxi) which he could not at the time refer to their appropriate genera. At the locality which I have designated as Chinkapin Hollow I have collected many very similar aments in immediate connection with, and in a few cases actually attached to, the scaly stems of *S. Sternbergianum.* We therefore now have, in addition to the foliage, the reproductive organs of both sexes of this plant. Moreover, as most of Professor Fontaine's specimens showing the foliage are from the Basal Potomac, and my Chinkapin Hollow locality also belongs to the Rappahannock series, while the aments described by him were found in the Aquia Creek series, the specimen now under consideration from the intermediate Mount Vernon beds establishes the complete geological continuity of this type throughout the whole of the Older Potomac.

The plant figured on Pl. IV, Figs. 5 and 6, is probably, as Professor Fontaine believes, his *Proteæphyllum reniforme*, but the nervation is very much better preserved and brings out the fine areolate character of the meshes in a clear light. A comparison of these specimens with one of Heer's figures of *Chondrophyllum orbiculatum* Heer (Fl. Foss. Arct., Vol. III, pt. 2, pl. xxxi, fig. 3*c*) makes it almost impossible to doubt that he had in hand either this same plant or a very near representative of it. This figure is not sufficiently like the other ones that he gives of *C. orbiculatum* to make it certain that they are the same. It is, however, an interesting fact that several species of Chondrophyllum have been detected in the Amboy Clays and in the Newer Potomac of Alabama and elsewhere. It is possible that when we come to confront all the data under this head we may be able to establish another of those bonds of union which bind together all the members of this great geologic group.

Finally, Figs. 7 and 8 of this same plate represent, according to Professor Fontaine, his *Menispermites virginiensis*, hitherto confined, as were all the Potomac species of the genus, to higher beds, this and *M. tenuinervis* Font. being Aquia Creek species. Dr. Hollick has, however, described two new species from the Amboy Clays, besides identifying the *M. borealis* of Heer. It is proper to say that Dr. Hollick, who saw these specimens, was disposed to refer them to Nelumbo; and I have considerable fragmentary material from the Mount Vernon Clay which indicates, with all necessary certainty, the presence of one or more species of that genus. It is just possible that this form may at least be allied to Nelumbo and represent an aquatic herb.

PLATE II.

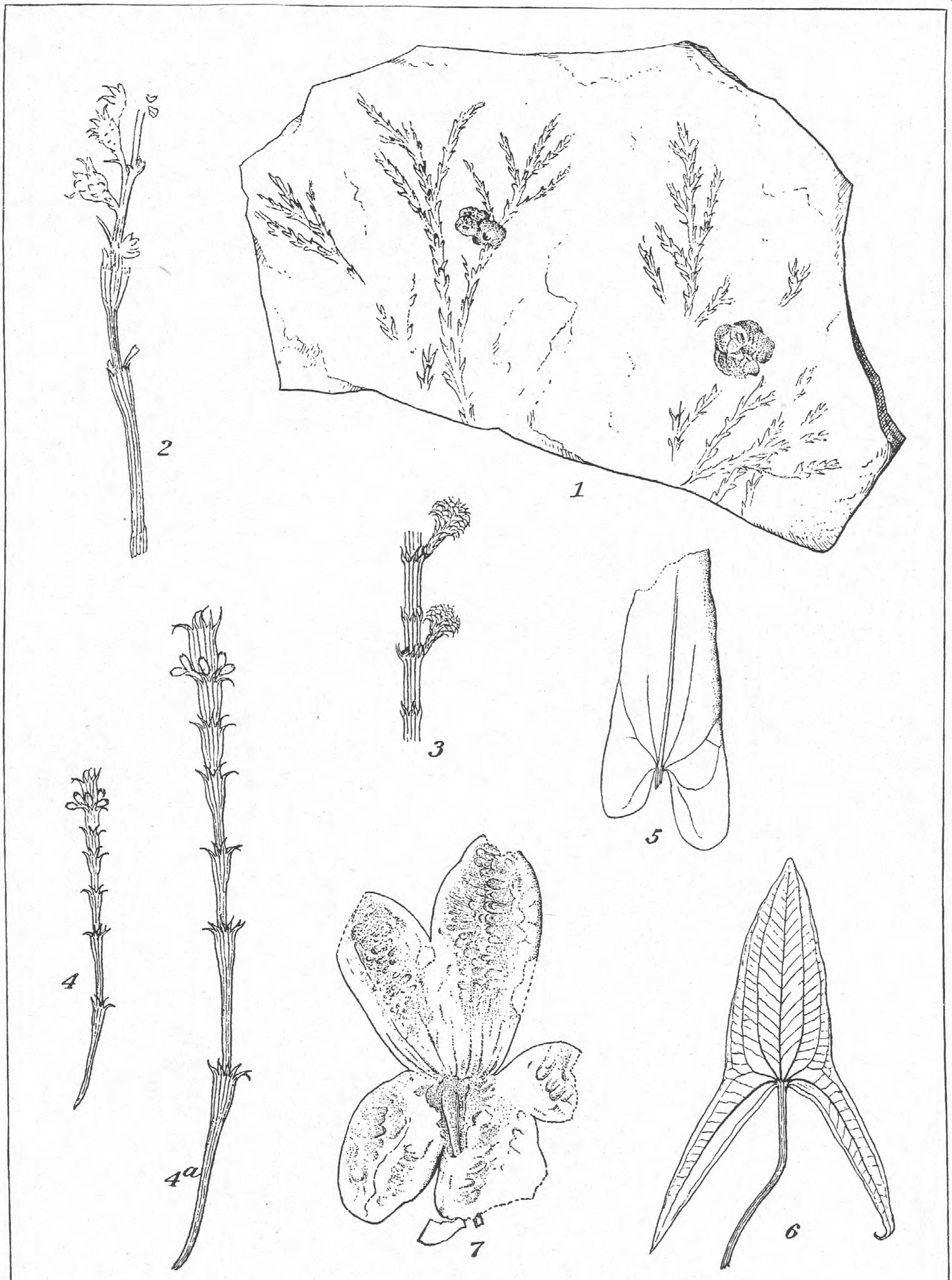
PLATE II.



MOUNT VERNON FLORA: CONIFERÆ, CASUARINACEÆ, MONOCOTYLEDONS.

PLATE III.

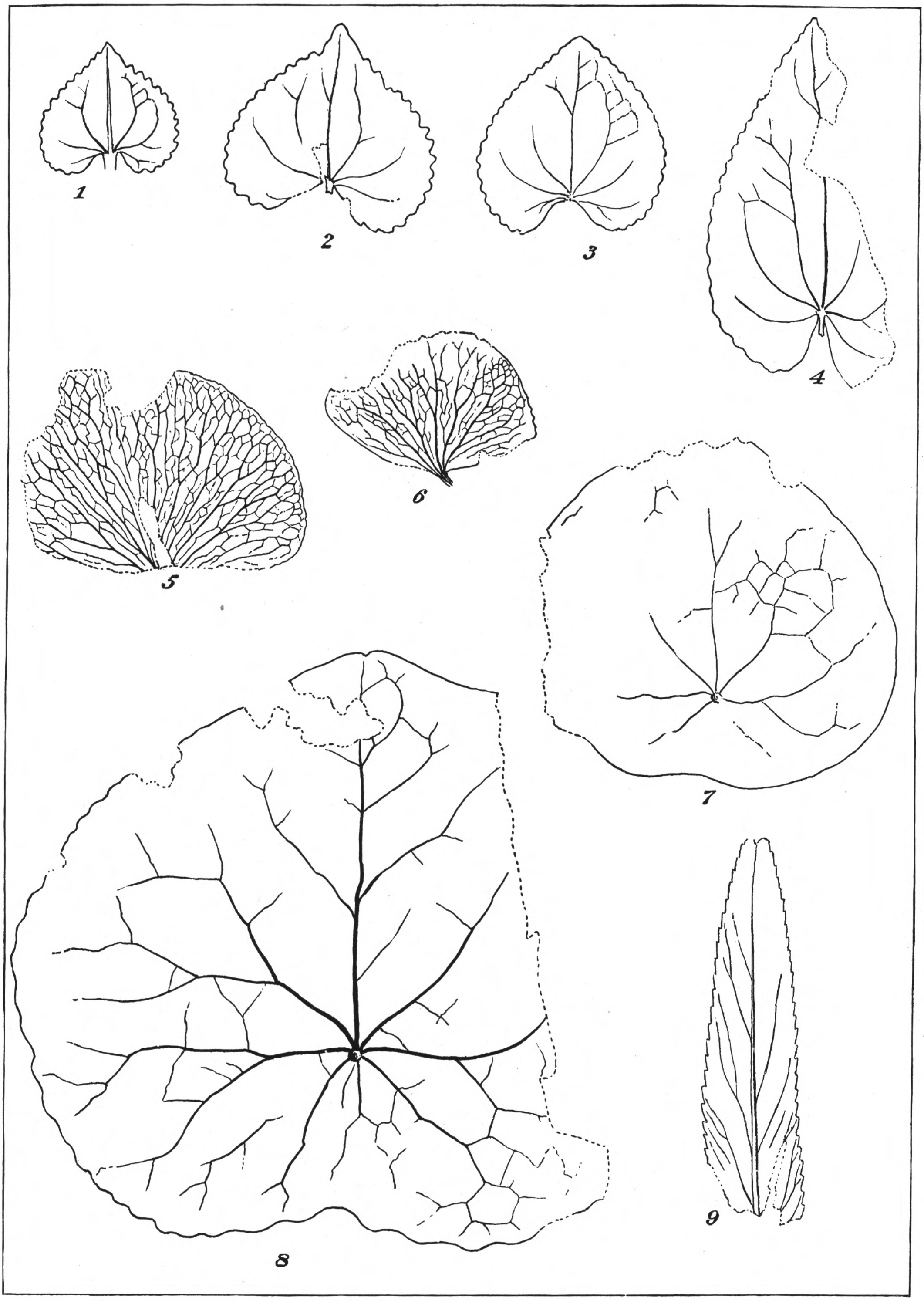
PLATE III.



MOUNT VERNON FLORA: CONIFERÆ, CASUARINACEÆ, MONOCOTYLEDONS.

PLATE IV.

PLATE IV.



MOUNT VERNON FLORA: D.COTYLEDONS.

THE AQUIA CREEK FLORA.

The Aquia Creek series has yielded 137 species, which is nearly 19 per cent of the total known Potomac flora. Of these, 57, or a little over 40 per cent, occur in the lower beds, while only 9, or less than 7 per cent, are found at a higher horizon. Sixty-seven, or nearly 49 per cent, are confined to that series. These facts show that notwithstanding the important interruption indicated by both the stratigraphy and the paleontology between the Basal Potomac and the Aquia Creek series, these beds must be classed with the former, as belonging to the more ancient deposits.

It might appear at first sight, when contemplating the well-marked dicotyledonous plants of the Mount Vernon Clays to which attention has been called, that they represent a flora as highly developed as that of the Aquia Creek series. But, as has been seen, the nervation of the species of Populus is different from that of any other known species of that genus. The Menispermites is an Aquia Creek species, the Proteæphyllum passes up from the Rappahannock into the Aquia Creek series, and the Celastrophyllum is quite anomalous. If we turn to the other types we find that they are either silent on the question or else that, as in the Scleropteris, they point back to the Upper Jurassic.

In our present limited knowledge of the Mount Vernon flora, therefore, we may say of the Aquia Creek series that we have here for the first time a well-marked dicotyledonous flora, in which both the form and nervation of the leaves begin to approximate those of modern times. Perhaps the most interesting genus is Celastropyllum, a type of plants with dentate or crenate leaves and nervation approaching that of the Celastraceæ. These forms can be traced throughout the entire Lower Cretaceous, one species, *C. proteoides* Font., occurring in the James River series, another, *C. arcinerve* Font., in the Rappahannock series, and I have already mentioned the two from the Mount Vernon Clays. But when we reach the Aquia Creek beds we find no less than ten distinct forms of this type, with their character much more highly developed. Four of these recur in the higher beds, though probably with slight modification in the same direction of greater definiteness, and this becomes one of the important types of the flora of the Amboy Clays and of all the beds of practically the same horizon, about eighteen different forms having been enumerated by Dr. Newberry and Dr. Hollick.

Another important genus of chiefly Aquia Creek plants is the Sapindopsis of Fontaine. This type was believed by him to have originated in the Rappahannock series, and two species, *S. cordata* Font. and *S. elliptica* Font., are described from Fredericksburg. The Aquia Creek series contains six species, all distinct from these, but presenting a somewhat varied and highly differentiated aspect. The leaves are not strictly pinnate, like those of Sapindus; although the lower leaflets are usually distinct, the upper ones are more commonly grown together so as to be rather lobed than pinnate. It is difficult to find the analogue of this feature in modern plants, except among the ferns and other low types; but I have seen leaves of *Rhus copallina* L. with the terminal leaflets confluent in this manner. This genus does not appear in the lists as recurring in the Amboy Clays, but Dr. Newberry's Fontainea is almost certainly its direct descendant, and should perhaps be classed in the same genus. These are the most common forms in the Aquia Creek series, and being so closely confined to it and so abundant, they constitute an excellent test of age wherever found.

The leading distinction, then, between this Middle Potomac flora and that of the Basal Potomac is in the predominance of dicotyledons; but the proof of its more direct connection with the lower beds consists in the persistence of simpler types—ferns, to some extent, but especially conifers. That peculiar intermediate genus, Nageiopsis, which seems almost to bridge over the interval between the cycad and the conifer, and of which fourteen species have been described, all occurring in the lower beds, illustrates this by the persistence of four of these species in the Aquia Creek series, and two of these, *N. angustifolia* Font. and *N. longifolia* Font., are found in the Mount Vernon Clays also. The last named has recently been detected in the Shasta group of California.

INTERMEDIATE FLORAS.

Up to the present date no fossil plants are known from the Iron Ore Clays proper. They consist of massive red clays, without lines of stratification, sand veins, or other evidences of interrupted sedimentation. In many places, especially in the iron ore regions, they abound in ferruginous crusts, and sometimes present regular shale, which, however, is obviously not the result of sedimentation, but represents lines along which the iron infiltration has been arrested and lithification has taken place. Concretions of all forms and regular geodes, together with all the multiform objects which characterize bog ore, are to be found; and sometimes there is to be seen upon such objects clear evidence of plant impressions, but always, so far as observed, of such a character as not to reveal the structure of the plant. When I first began my investigations, after having carefully studied the Fredericksburg freestone as seen at Alum Rock and other points, containing so many impressions of stems and even large trunks, but without showing the more delicate organs, and then subsequently examining the Iron Ore Clays and finding similar impressions in them, I framed the theory that the Iron Ore Clays of Maryland might be the more northern homologue of the Virginia freestone; although the former is always white and destitute of iron, while the latter is always red or brown and charged with the iron oxide. But a more thorough acquaintance with the general region of the Iron Ore Clays soon showed me the impossibility of this, and revealed the fact that the true Rappahannock series, resembling in most respects, except that of actual lithification, the more southern exposures, is always to be found underneath the red clays. This has already been sufficiently dwelt upon, and it need only be added that the greater part of these impressions of plants are observed to occur near the line of contact between the clays and the underlying sands (paint stone, etc.), so that it is usually a question to which of these series such impressions actually belong. Of course, under such circumstances I am disposed to assume that they probably belong to the lower of the two beds, in which case they would really be the homologue of those found in the Rappahannock freestone. It therefore becomes all the more probable that the Iron Ore Clays proper may contain no fossil plants.

THE LOWER ALBIRUPEAN FLORA.

The question, then, arises whether there are any beds from which fossil plants have been obtained which can be regarded as truly intermediate between the Aquia Creek series and the Amboy Clays and their equivalents. As I have already intimated, the several plant-bearing horizons belonging to the Albirupean series in the State of Maryland and the District of Columbia very probably represent those of the Raritan formation of New Jersey, which may be regarded as an immense thickening of them. The fact that in the limited collections from the Maryland beds so many of the forms are identical with or similar to those of the Amboy Clays seems to prove this, and while these more southern deposits may differ considerably in their geological position, the same is certainly true of the New Jersey deposits, those of Woodbridge, Sayreville, and Milltown being undoubtedly considerably lower than those of South Amboy, while a marked difference is often to be noticed in the horizon at which plants are found in the same clay pit, as some of these pits have a depth of 100 feet or more.

There are only two localities which I have suspected of occupying some such intermediate position. One of these is the plant bed on Pennsylvania avenue extended, in the District of Columbia, near the Anacostia River. There are here really two localities at the same horizon, not more than half a mile apart. The one which has yielded most of the plants is just below the crest of the hill, in a deep cutting made for the roadway. The plants came from the vein not over 10 feet above the top of the red clays, which undoubtedly belong to the Iron Ore series. But it is also not over 10 or 15 feet below the Miocene (Chesapeake) which caps the hill. Indeed, the Chesapeake formation at this point contains at its base a great many clay pellets redeposited from the Potomac, and in some of these, 20 feet above the plant layer, impressions of leaves evidently of Potomac plants were once found by Dr. Rothpletz and myself.

At one restricted horizon in this thin Upper Potomac bed a large collection of plants was made. They are very fragmentary, the clays breaking easily across, so as to render it impossible to obtain large

that it has been sought to accomplish is the identification of the forms from other localities with these last. The localities from which collections have been made for such comparison, taken in their order from southwest to northeast, are as follows:

1. The great railroad cutting near Pocahontas, in Tennessee, which has been many times visited by geologists and the age of which was never settled until the summer of 1891, when Mr. McGee's party visited it, has yielded one species, collected at that time by Prof. Robert T. Hill, which proves to be the *Eucalyptus attenuata* of Newberry. Mr. McGee, upon the stratigraphical evidence presented, pronounced the formation Cretaceous, and Professor Hill's specimen practically fixes it as the equivalent of the Tuscaloosa formation.

2. Locality on the Kansas City, Memphis, and Birmingham Railroad in Alabama, at Glen Allen, this being the name of the railroad station. From this locality a large collection was made by Dr. Eugene A. Smith and myself in 1892, and more than 20 of the species in that collection have been either identified with or found to be closely related to Amboy Clay species.

3. At Shirley's mill, on Davis Creek, 11 miles south of Fayetteville, in Fayette County, Ala., a still larger collection was made during the same expedition. The specimens are in an admirable state of preservation and over 50 species have been provisionally identified, chiefly with Amboy Clay forms.

4. At three localities in or near the city of Tuscaloosa 7 or 8 species have been partially identified.

5. Near Cottondale, 8 miles east of Tuscaloosa, Professor Fontaine made a large collection in 1887. This has yielded about 40 more or less determinable forms, most of which are compared with Amboy Clay species.

6. Near Brightseat, Md., 10 miles east of Washington, 3 of the species of sassafras found in the Amboy Clays have been collected.

7. On the abandoned Drum Point Railroad, near where it crosses Severn Run, 5 different forms were collected by Mr. David White, which can be compared with those of the Amboy Clays, and some of which are probably specifically identical.

8. At Round Bay, on the north side of the Severn River, half a mile above the landing, some dark carbonaceous shales and clays, only a few feet above tide, have yielded about a dozen plants which are clearly of Amboy types. Notable among these is the *Fontainea grandifolia* of Newberry. At least 2 species of Andromeda, *A. Parlatorii* Heer and *A. flexuosa* Newb., also certainly occur, as do *Widdringtonites Reichii* (Ett.) Heer, *Chondrites flexuosa* Newb., *Czekanowskia capillaris* Newb., and *Gleichenia micromera* Heer. A number of other forms were provisionally identified.

9. In the bluff a short distance above the pavilion on Round Bay and immediately underneath the overlying marine Cretaceous is a thin,

light-colored clay layer in which *Eucalyptus nervosa* Newb., *E. attenuata* Newb., and several other Amboy Clay types were collected. This bluff is about 20 feet high, and allowing for the dip the plant bed is probably 30 or 40 feet above the last named.

10. A short distance below Bodkin Point, which lies below the mouth of the Patapsco, clay layers similar to those last described and having nearly the same relation with the marine Cretaceous have yielded *Eucalyptus attenuata* Newb., *Andromeda latifolia* Newb., *A. Parlatorii* Heer, *Myrsine borealis* Heer, and *Sequoia Reichenbachi* (Gein.) Heer, all of which are found in the Amboy Clays.

11. The most important plant bed in Maryland at this horizon is that of Grove Point at the mouth of the Sassafras River, on the eastern shore of the Chesapeake Bay. It has yielded about 40 species, nearly all of which have been identified with Amboy Clay forms embracing the greater part of the characteristic species of the New Jersey beds. The plant bed, which is in rather coarse arenaceous clay situated near the water's edge, rises some 10 to 15 feet and is overlain by the Clay Marls, which are here quite thin, but are developed to a great thickness on the opposite side of the Sassafras River between Betterton and Howell's Point. This locality has the further advantage of having its stratigraphical position clearly shown. Perhaps the most instructive section of the Potomac formation that has been discovered is that which I have called the Chesapeake section; it can be worked out very satisfactorily from the Baltimore and Ohio Railroad between Foys Hill and the Little Elk River, southward to the mouth of Principio Creek and thence along the eastern shore of Northeast River, Elk River, and the bay to the Sassafras. The fine bluffs along these shores show the gradual ascent of the Potomac strata through the entire thickness of the great clay series to where they finally dip beneath the water a short distance above Betterton and pass under the Clay Marls and marine Cretaceous deposits. In this section we have every phase of the Potomac formation, from the lilac clays of the James River series to the top of the Albirupean. It is probable that the Raritan section merely represents a great thickening of the upper clay series and that the Grove Point plant bed corresponds with similar strata which may be seen a short distance east of South Amboy and also in some of the clay pits occupying an elevated position directly south of that place.

I shall not include in this enumeration the several collections that have been made by Mr. David White, Mr. Charles H. Meade, and myself in the Raritan region, although many of our specimens have proved to be the same as those studied by Dr. Newberry. I shall also pass over Dr. Hollick's collections from Staten Island and Long Island, and Mr. White's collections from Long Island, because these have been for the most part published.

12. The extensive collections which were made by Mr. David White on Marthas Vineyard, chiefly at Gay Head, but also in the Weyquosque

cliff on the south shore of the island, at Indian Head, and several other localities, have also been subjected to a careful comparison with the flora of the Amboy Clays, and are found to agree in a large number of the forms obtained. As has been previously stated, these plants occur in a different matrix from that of any that have been collected on the Raritan, viz, in ferruginous nodules embedded in the clays. Dr. Newberry mentions vegetable remains in such nodules at Keyport, which is the most easterly point at which any plants have been found in the Raritan section, and therefore presumably represents a higher horizon.[1] As already remarked (supra, p. 335), all the plant beds of Staten Island, Long Island, and Marthas Vineyard, constituting the Island series, consist of clays containing ferruginous nodules which hold the impressions, and probably represent a somewhat higher horizon and the highest thus far known in the Potomac formation. That there is no very wide distinction between them and the Raritan beds is proved by the recurrence of so large a number of Amboy Clay species. Most of the characteristic types are found here, but with them are others which have a somewhat modern facies. The genus Liriodendropsis, with its peculiar areolate nervation, may be regarded as a dominant type of these higher beds, and probably there will be found to be 5 or 6 species of that form, though the *L. simplex* Newb. and *L. angustifolia* Newb. are the most abundant.

The statement has been made[2] that in Dr. Hollick's recent enumerations of the Cretaceous plants of Long Island[3] he has identified 23 out of the 50 species known with those of the Dakota group. Such an inference might, it is true, be hastily drawn from his table of distribution, but to say that a species has been reported from the Dakota group is a very different thing from saying that it is a Dakota group species. It is certainly not correct to say that 23 out of the 50 species found on Long Island are Dakota group species. A slight inspection of his table shows that 12 of these are Greenland species named by Heer, which Lesquereux supposed that he detected in the Dakota group. Some of his identifications are doubtless correct, but a number of them are doubtful, and to several he has himself affixed query marks. It has already been sufficiently shown that there is a close affinity between the Amboy Clay flora and that of the Cretaceous of Greenland. It is probable that the latter constitutes a simple continuation of the Cretaceous of the Atlantic border, and therefore the flora would naturally be similar. Even if the Atane beds are higher than the highest American

---

[1]Dr. Newberry's specimens are supposed to have come from the bluff under Cliffwood, across the Matawan from Keyport. On July 26, 1894, I visited this bluff in company with Dr. N. L. Britton and Dr. Arthur Hollick. We found the lower portion of it to consist of marine Cretaceous beds belonging to the Clay Marls or the Matawan formation, in which vegetable remains in a fair state of preservation occur.

[2]Am. Jour. Sci., 3d ser., Vol. XLVII, May, 1894, p. 402.

[3]Some Further Notes on the Geology of the North Shore of Long Island, Trans. N. Y. Acad. Sci., Vol. XIII, 1894 (Contributions from the Geological Department of Columbia College, No. XVIII, second paper, Jan. 22, 1894), pp. 122–132. See Table of Distribution facing p. 130.

strata, the flora would contain the immediate descendants of the former, and many of the same species would persist. This has been sufficiently shown by Dr. Newberry in his Flora of the Amboy Clays, now in press, and is no argument that the Amboy Clays are not somewhat lower than these beds.

In the second place, it must be admitted that Dr. Hollick has identified a number of these with true Dakota group plants on entirely too imperfect material. For example, his *Salix proteæfolia flexuosa* can scarcely be that of Lesquereux and should have been made a new species. His *Sassafras acutilobum* lacks the lobes by which alone it could be identified, and the base is not precisely that of Lesquereux's plant. His *Leguminosites convolutus*, which he himself questions, is based upon a very small fragment of the lower portion, which might be that of either *L. convolutus* Lx. or *L. constrictus* Lx., and the leaf that he identified with the last named has a wedge-shaped or acute base and can not belong to that species. The leaf which he doubtfully refers to Lesquereux's *Celastrophyllum decurrens*, but which lacks the margins necessary for its identification, seems to me to have the areolate nervation of a Liriodendropsis. Finally, one species, *Liriodendron simplex* Newb., which Dr. Newberry changed to Liriodondropsis on account of the nervation, is not found in the Dakota group at all. With the exception, therefore, of *Proteoides daphnogenoides* Heer, *Diospyros rotundifolia* Lx., and probably *Liriodendron primævum* Newb., all of the 23 species enumerated in Dr. Hollick's list as found in the Dakota group are either Greenland species or are of doubtful identification.

Dr. Hollick's inclination to identify Eastern Cretaceous plants with remote forms described from Europe or western America, at higher horizons, though doubtless due to a laudable desire to avoid the multiplication of species, is based upon a thoroughly false principle and must necessarily lead to great confusion. Upon mere fragments he has announced the occurrence in the Cretaceous of Long Island of *Celastrophyllum Benedeni* Sap. and Mar., from the Gelinden beds of Belgium, lowest Eocene, and *Grewiopsis viburnifolia* Ward, from the Fort Union group of Montana. A comparison of these cases shows that this is not justifiable in either of them. The only sound principle is that such remote and improbable identifications should be made only where the evidence is overwhelming. Doubtful forms, if worth recording at all, should be treated as new. If they are subsequently found to belong to known species it is much easier to combine them than it is to separate them from species to which they do not belong. So that, aside from the danger of furnishing the basis for false generalizations, which is the principal consideration, the interests of literature and taxonomy demand that great care be exercised in such matters.

The number of species thus far determined from all the beds that I have included in the Albirupean amounts to 347, or 47 per cent of the total known Potomac flora. This is therefore much the largest of all the floras thus far enumerated. It is larger than the combined James River and Rappahannock floras, which, when the forms common to the two are deducted, aggregates 305 species. If to these we add the Mount Vernon and Aquia Creek species not found below, 99 in number, we have for the Older Potomac 405 species, or 55 per cent. As most of the undetermined material is from the Newer Potomac, it may be roughly stated that the Older and Newer Potomac have at the present time each about the same number of species in the collections. But the striking fact is the small number of Older Potomac forms that ever reach these higher beds. Only 15 such forms have been detected, or a little more than 4 per cent of the latter flora. This certainly indicates, from the paleontological standpoint alone, a radical difference between the lower and the upper beds. The intermediate horizons, which I have considered, only partially remove these difficulties. Were it not that it is impossible to discover any clear stratigraphical interval, any evidence of a great time hiatus, any general erosion plane, even such as occurs between the Rappahannock and Aquia Creek series, we should certainly be justified, from paleontological considerations alone, in dividing this great geological unit into two distinct formations. But in the absence of such stratigraphical distinctions we are obliged to treat it as a whole, and when we remember that the great clay series, beginning with the base of the Iron Ore Clays and extending to the Alternating Clay-Sands of the upper beds, is, so far as known, wholly nonfossiliferous, we are obliged to conclude that it was during the long period required to deposit these beds, a period that may have been much more extended than that which would be required to deposit a greater thickness of sand and gravel, that the radical change took place between the chiefly filicine, cycadean, and coniferous flora of the Older Potomac and the chiefly dicotyledonous flora of the Newer Potomac.

The numerical relations of the several subfloras of the Potomac formation, as above set forth, may be presented in the following tabular form:

	Number of species.	Per cent of total.
Potomac flora	737	....
A. Older Potomac	405	55
I. Basal Potomac	329	44.6
1. James River	152	20.6
2. Rappahannock	221	30
3. Mount Vernon	42	5.7
II. Middle Potomac	137	18.6
4. Aquia Creek	137	18.6
B. Newer Potomac	347	47.1
5. Lower Albirupean	31	4.2
6. Amboy Clays and equivalents	253	34.2
7. Island series	133	18

CORRELATION OF THE FLORAS.

In the following correlation of the several floras of the Potomac formation I shall confine myself entirely to their internal relations and leave out of the account, for the present, the general subject of foreign distribution.

As already stated, the total flora thus far enumerated embraces 737 distinct forms. Some of these are not yet specifically determined, while a few are treated as varieties. To avoid multiplication of words the term "species" will be used for them all. As always happens, especially in floras as unique as that of the Potomac, the greater part of these are more or less rare and are confined to a single horizon, often to a single locality; in many cases only one specimem has been found. These, of course, are not available for purposes of correlation, and it will be necessary to confine the discussion to those species which are common to at least two of the six series into which the formation has been subdivided. The number of species that come under this head is 140, or 19 per cent of the total flora. The question of relative abundance has already been considered, and we are now restricted to the numerical relations alone. These have been stated in a general way in discussing the several series. It is now proposed to enumerate the plants that come under the leading groups forming the elements of this correlation. The object is to show what plants are common to two or more of the series, and it will be convenient, as before, to deal with the lowest members first, and with the others in their ascending order.

It was seen that 44 species were confined to the Basal Potomac, but occur in both of its members. These are as follows:

SPECIES COMMON TO THE JAMES RIVER AND RAPPAHANNOCK SERIES NOT OCCURRING ABOVE.

Acrostichopteris parcelobata Font.
Anomozamites virginica Font.
Aspidium angustipinnatum Font.
dentatum Font.
Dunkeri (Schimp.) Font.
fredericksburgense Font.
parvifolium Font.
Athrotaxopsis expansa Font.
Baiera adiantifolia Font.
expansa Font.
Brachyphyllum parceramosum Font.
Cephalotaxopsis magnifolia Font.
microphylla Font.
Cladophlebis acuta Font.
brevipennis Font.
oblongifolia Font.
petiolata Font.
Cupressinoxylon Wardi Kn.
Cycadeospermum ellipticum Font.
obovatum Font.
Equisetum Lyelli Mant.
virginicum Font.
Nageiopsis heterophylla Font.
latifolia Font.
microphylla Font.
recurvata Font.
Pecopteris microdonta Font.
ovatodentata Font.
Proteæphyllum tenuinerve Font.
Rogersia longifolia Font.
Scleropteris elliptica Font.
virginica Font.
Sequoia Reichenbachi longifolia Font.
Sphenolepidium recurvifolium Font.
Sphenopteris thyrsopteroides Font.
Thyrsopteris dentata Font.
divaricata Font.
elliptica Font.
microloba alata Font.
nana Font.
obtusiloba Font.
rhombiloba Font.
squarrosa Font.
Zamites ovalis Font.

The Basal Potomac species that pass up into higher series may be considered with reference to whether they occur in the Mount Vernon Clays, in the Aquia Creek series, or in the Newer Potomac. The following is a list of 19 species that have their origin in the Basal Potomac and recur in the Mount Vernon Clays:

SPECIES PASSING UP FROM THE BASAL POTOMAC INTO THE MOUNT VERNON CLAYS.

Aspidium virginicum Font.
Cladophlebis constricta Font.
 rotundata Font.
Ficophyllum tenuinerve Font.
Gleichenia Nordenskiöldi Heer.
Glyptostrobus brookensis Font.
Myrica brookensis Font.
Nageiopsis angustifolia Font.
 longifolia Font.
Proteæphyllum reniforme Font.
Rogersia angustifolia Font.
Sphenolepidium Sternbergianum (Dunk.) Heer.
Sphenopteris latiloba Font.
Thyrsopteris bella Font.
 brevifolia Font.
 decurrens Font.
 rarinervis Font.
Zamites crassinervis Font.
 tenuinervis Font.

The following 15 species are common to the Mount Vernon and Aquia Creek series:

SPECIES COMMON TO THE MOUNT VERNON CLAYS AND THE AQUIA CREEK SERIES.

Aspidium virginicum Font.[1]
Baieropsis denticulata angustifolia Font.
Celastrophyllum Brittonianum Hollick?
Cladophlebis constricta Font.[1]
Glyptostrobus brookensis Font.[1]
Menispermites virginiensis Font.
Myrica brookensis Font.[1]
Nageiopsis angustifolia Font.[1]
Nageiopsis longifolia Font.[1]
Proteæphyllum reniforme Font.[1]
Rogersia angustifolia Font.[1]
Sphenopteris latiloba Font.[1]
Thyrsopteris bella Font.[1]
 decurrens Font.[1]
 rarinervis Font.[1]

Four species are found in both the Mount Vernon Clays and the Newer Potomac, as follows:

SPECIES COMMON TO THE MOUNT VERNON CLAYS AND THE NEWER POTOMAC.

Celastrophyllum Brittonianum Hollick?
Myrica brookensis Font.
Podozamites marginatus Heer.
Sphenopteris grevillioides Heer.

Only 6 Aquia Creek species, that is, species originating in the Aquia Creek series, are found in the Newer Potomac.

SPECIES COMMON AND CONFINED TO THE AQUIA CREEK SERIES AND THE NEWER POTOMAC.

Araliæphyllum acutilobum Font.
Celastrophyllum denticulatum Font.
 latifolium Font.
Celastrophyllum robustum Newb.
 undulatum Newb.
Populophyllum crassinerve Font.

Finally there are 6 species originating in the Basal Potomac which are also found in the Newer Potomac.

BASAL POTOMAC SPECIES PASSING UP INTO THE NEWER POTOMAC.

Cladophlebis parva Font.
Myrica brookensis Font.
Sequoia ambigua Heer.
Sequoia Reichenbachi (Gein.) Heer.
 rigida Heer.
 subulata Heer.

[1]Twelve of these, it will be seen, are common to this and the preceding list, i. e., they are species that pass up from the Basal Potomac through the Mount Vernon beds into the Aquia Creek. There may therefore be said to be 6 Basal Potomac species that terminate in the Mount Vernon Clays, and 3 species that originate there.

The flora of the two localities which were treated as intermediate really shows that they belong to the Albirupean series, but may be somewhat lower than any of the other beds in that series. Eight of the species are confined to those localities, but there are 3 species not found in any of the higher beds which have their origin in the Older Potomac. They are the following:

OLDER POTOMAC SPECIES RECURRING IN THE LOWER ALBIRUPEAN AND NOT FOUND HIGHER.

Cladophlebis parva Font.
Populophyllum crassinerve Font.
Sequoia ambigua Heer.

There are 3 others that pass up from the Older Potomac and are found in both the Lower and Upper Albirupean, as follows:

OLDER POTOMAC SPECIES RECURRING IN THE LOWER ALBIRUPEAN AND ALSO FOUND HIGHER.

Celastrophyllum undulatum Newb.
Sequoia Reichenbachi (Gein.) Heer.
subulata Heer.

The last 5 lists embrace the 15 species of the Newer Potomac that have their origin in the Older Potomac, but as they recur in the different lists, and as this is one of the most important facts in the correlation, it seems best, at the risk of repetition, to reproduce this list by itself. The following are the species:

SPECIES COMMON TO THE OLDER AND NEWER POTOMAC.

Araliæphyllum acutilobum Font.	Podozamites marginatus Heer.
Celastrophyllum Brittonianum Hollick?	Populophyllum crassinerve Font.
denticulatum Font.	Sequoia ambigua Heer.
latifolium Font.	Reichenbachi (Gein.) Heer.
robustum Newb.	rigida Heer.
undulatum Newb.	subulata Heer.
Cladophlebis parva Font.	Sphenopteris grevillioides Heer.
Myrica brookensis Font.	

These 15 species constitute the entire bond that unites the Older and Newer Potomac so far as species are concerned. That this bond may be strengthened by further discoveries is altogether probable, but it is especially desirable that plant-bearing beds be found and developed at intermediate horizons, such as are represented by the Iron Ore Clays.

The remaining 17 species are common to the Lower and Upper Albirupean and are not found at a lower horizon.

SPECIES OCCURRING IN THE LOWER AND UPPER ALBIRUPEAN AND NOT FOUND LOWER.

Andromeda latifolia Newb.	Podozamites sp. Hollick.
Asplenium Dicksonianum Heer.	Proteoides daphnogenoides Heer.
Celastrophyllum crenatum Heer.	Sassafras acutilobum Lx.
Chondrophyllum reticulatum Hollick.	hastatum Newb.
Czekanowskia capillaris Newb.	rotundilobum Newb.
Eucalyptus attenuata Newb.	Sequoia gracillima (Lx.) Newb.
parvifolia Newb.	heterophylla Vel.
Juniperus macilenta Heer.	Tricalycites papyraceus Newb.
Myrsine borealis Heer.	

The following general table of distribution of the 140 species common to two or more of the great series of the Potomac formation will bring out the above relations in a somewhat more compact form:

Table of distribution of the species of Potomac plants occurring in two or more of the six primary subdivisions of the formation.

Species.	Older Potomac.				Newer Potomac.	
	Basal Potomac.			Middle Potomac.		
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.
Abietites angusticarpus Font		+		+		
Acrostichopteris densifolia Font	+			?		
parcelobata Font	+	+				
parvifolia Font	+			?		
Andromeda latifolia Newb					+	+
Anomozamites angustifolius Font		+		+		
virginicus Font	+	+				
Araliæphyllum acutilobum Font				+		?
Araucarites aquiensis Font		?		+		
Aspidium angustipinnatum Font	+	+				
dentatum Font	+	+				
Dunkeri (Schimp) Font	+	+				
ellipticum Font		+		+		
fredericksburgense Font	+	+				
parvifolium Font	+	+				
virginicum Font		+	+	+		
Asplenium Dicksonianum Heer					+	+
Athrotaxopsis expansa Font	+	+				
grandis Font		+		+		
tenuicaulis Font	+	+		+		
Baieropsis adiantifolia Font	+	+				
denticulata angustifolia Font			+	+		
expansa Font	+	+				
Brachyphyllum crassicaule Font	+			+		
parceramosum Font	+	?				
Carpolithus brookensis Font	+			+		
Celastrophyllum Brittonianum Hollick			?	?		+
crenatum Heer					+	+
denticulatum Font				+		+
latifolium Font				+		+
robustum Newb				?		+
undulatum Newb				+	+	+
Cephalotaxopsis magnifolia Font	+	+				
microphylla Font	+	+				
Chondrophyllum reticulatum Hollick					+	+
Cladophlebis acuta Font	+	+				
brevipennis Font	+	+				
constricta Font		+	?	+		
crenata Font		+		+		
oblongifolia Font	+	+				
parva Font		+			+	
petiolata Font	+	+				
rotundata Font		+	?			
? sp. Font		+		+		
Cupressinoxylon Wardi Kn	+	+				
Cycadeospermum ellipticum Font	+	+				
obovatum Font	+	+				

Table of the distribution of the species of Potomac plants, etc.—Continued.

Species.	Older Potomac.				Newer Potomac.	
	Basal Potomac.			Middle Potomac.		
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.
Czekanowskia capillaris Newb					?	+
Dioonites Buchianus (Ett.) Born	+	+		?		
Equisetum Lyelli Mant	+	+				
marylandicum Font		+		+		
virginicum Font	+	?				
Eucalyptus attenuata Newb					+	+
parvifolia Newb					+	+
Ficophyllum crassinerve Font	+	+		+		
serratum Font		+		+		
tenuinerve Font		+	+			
Gleichenia Nordenskiöldi Heer	+	+	+			
Glyptostrobus brookensis Font	?		+	+		
fastigiatus Font		+		+		
Juniperus macilenta Heer					?	+
Leptostrobus longifolius Font	+	+		+		
Menispermites virginiensis Font			+	+		
Myrica brookensis Font		+	+	+		?
Myrsine borealis Heer					+	+
Nageiopsis angustifolia Font	+	+	?	+		
crassicaulis Font	+	+		+		
heterophylla Font	+	+				
latifolia Font	+	+				
longifolia Font	+	+	+	+		
microphylla Font	+	+				
recurvata Font	+	+				
zamioides Font	+	+		+		
Pecopteris Browniana Dunk	+	+		?		
microdonta Font	+	+				
ovatodentata Font	+	+				
strictinervis Font		+		?		
virginiensis Font	+	+		+		
Podozamites acutifolius Font	+	+		+		
distantinervis Font	+	+		?		
marginatus Heer			?			?
pedicellatus Font		+		?		
sp. Hollick					+	+
Populophyllum crassinerve Font				+	+	
Proteæphyllum reniforme Font		+	+	+		
tenuinerve Font	+	+				
Proteoides daphnogenoides Heer					+	+
Rogersia angustifolia Font		+	+	+		
longifolia Font	+	+				
Sagenopteris elliptica Font	+	+		?		
Saliciphyllum ellipticum Font	+	+		+		
Sassafras acutilobum Lx					+	+
hastatum Newb					+	+
(Araliopsis) rotundilobum Newb					+	+
Scleropteris elliptica Font	+	+				
virginica Font	+	+				
Sequoia ambigua Heer	+				?	
gracillima (Lx.) Newb					+	+
heterophylla Vel					+	+
Reichenbachi (Gein.) Heer	+	+		+	+	+
longifolia Font	+	+				

Table of distribution of the species of Potomac plants, etc.—Continued.

Species.	Older Potomac.				Newer Potomac.	
	Basal Potomac.			Middle Potomac.		
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.
Sequoia rigida Heer	+	+				+
subulata Heer	+	+			+	+
? sp. Font		+		+		
Sphenolepidium Kurrianum (Dunk.) Heer	+			+		
parceramosum Font		+		+		
recurvifolium Font	+	+				
Sternbergianum (Dunk.) Heer		+	+			
Sternbergianum densifolium Font	+	+		+		
virginicum Font		+		+		
Sphenopteris acrodentata Font	+			?		
grevillioides Heer			+			+
latiloba Font	+	+	?	+		
thyrsopteroides Font	+	+				
Thinnfeldia variabilis Font		+		+		
Thyrsopteris angustifolia Font	+	+		+		
angustiloba Font	+	+		+		
bella Font	+	+	+	+		
brevifolia Font	+		+			
brevipennis Font	+			+		
decurrens Font	+	+	+	+		
densifolia Font		+		+		
dentata Font	+	+				
divaricata Font	+	+				
elliptica Font	+	+				
Meekiana Font	+	+		+		
angustiloba Font	+	+		+		
microloba alata Font	+	+				
nana Font	+	+				
obtusiloba Font	+	+				
pachyrachis Font	+	+		?		
rarinervis Font	+	+	+	+		
rhombifolia Font		+		?		
rhombiloba Font	+	+				
squarrosa Font	+	+				
Tricalycites papyraceus Newb					+	+
Zamiopsis petiolata Font		+		?		
Zamites crassinervis Font		+	?			
ovalis Font	+	+				
tenuinervis Font	+	+	+			

In this table I have not separated the Island series from the rest of the Upper Albirupean, because, as already stated, the great similarity in the flora scarcely seems to warrant this. To show this more clearly I introduce here the following list of 52 species common to the Island series and other localities in the Upper Albirupean:

Acer amboyensis Newb.
Andromeda Novæ-Cæsareæ Hollick.
Parlatorii Heer.
Aralia patens Newb.
Asplenium Dicksonianum Heer.
Celastrophyllum grandifolium Newb.
undulatum Newb.
Cissites formosus Heer.
Colutea primordialis Heer.
Dammara borealis Heer.
Diospyros primæva Heer.
rotundifolia Lx.
Eucalyptus attenuata Newb.
Geinitzi Heer.
nervosa Newb.
Ficus atavina Heer.
Woolsoni Newb.
Hymenæa dakotana Lx.
Juglans arctica Heer.
crassipes Heer.
Laurophyllum lanceolatum Newb.
Laurus Plutonia Heer.
Liriodendron oblongifolium Newb.
Liriodendropsis angustifolia Newb.
simplex Lx.
Magnolia auriculata Newb.
Magnolia Capellinii Heer.
glaucoides Newb.
longifolia Newb.
longipes Newb.
speciosa Heer.
Myrica brookensis Font.
Hollicki Ward.
Newberryana Hollick.
Myrisine elongata Hollick.
Phyllites poinsettioides Hollick.
Populus? apiculata Newb.
Proteoides daphnogenoides Heer.
Salix proteæfolia Lx.
Sapindus Morrisii Lx.
Sassafras acutilobum Lx.
progenitor Newb.
rotundilobum Newb.
Sequoia ambigua Heer.
gracillima (Lx.) Newb.
heterophylla Vel.
Reichenbachi (Gein.) Heer.
Thinnfeldia Lesquereuxiana Heer.
Tricalycites papyraceus Newb.
Viburnum integrifolium Newb.
Widdringtonites Reichii (Ett.) Heer.
Williamsonia problematica Newb.

BOTANICAL CHARACTERS OF THE POTOMAC FLORA.

Thus far we have considered the Potomac formation as a whole without reference to botanical classification. This aspect of the subject may now be taken into account. It may be said in general that the flora consists chiefly of ferns, cycads, conifers, and dicotyledons. Only three cellular cryptogams have been described, all of which are more or less doubtful from the imperfect condition of their preservation. The genus Equisetum is represented by 7 species, not all of which are well defined. One species has been referred to the genus Casuarina, and 7 different forms, some of them with more or less doubt, to the monocotyledons, 2 of the latter being supposed to be palms. Besides these there are 39 forms whose botanical affinities can not be determined, 25 of which consist of fruits and seeds which have been grouped together under the general name of Carpolithus and which can not now be referred, with any certainty, to their respective genera. Leaving all of these out of the account, we find the ferns represented by 31 genera and 161 species, constituting nearly 22 per cent of the total flora; the Cycadaceæ by 14 genera and 44 species, or 6 per cent of the flora; the Coniferæ by 34 genera and 146 species, or nearly 20 per cent of the flora; and the dicotyledons by 92 genera and 330 species, or slightly less than 45 per cent of the flora.

Most of the genera of ferns are represented by only a few species, and the greater number of the species belong to the following 7 genera: Angiopteridium 9 species, Aspidium 14 species, Cladophlebis 22 species, Ctenopteris 6 species, Pecopteris 10 species, Sphenopteris 7 species, and Thyrsopteris 40 species. In all but 2 of these genera the species are confined to the Older Potomac. All the species of Angiopteridium come from the Rappahannock series. Three species of Aspidium occur in the Aquia Creek series, 1 in the Mount Vernon Clays, and the rest are about equally distributed between the two basal series. Cladophlebis belongs chiefly to the Basal Potomac, but 2 species occur in the Mount Vernon Clays, 3 in the Aquia Creek series, and 1 species, *C. parva* Font., is represented in the collection from Snow's plantation, which I have considered as belonging to the Lower Albirupean. This is originally a Rappahannock species, but it is also found in the Kootanie. The 6 species of Ctenopteris are all confined to the Rappahannock series. All the forms that have been united with the Paleozoic species Pecopteris are found in the Older Potomac, and 4 pass up into the Aquia Creek series. Only 2 of the 8 species of Sphenopteris occur in the Newer Potomac, and both of these are involved in some doubt. *S. latiloba* Font. is the most common and is found in all four of the Older Potomac series.

The genus Thyrsopteris has the greatest interest of all the genera of ferns, and in many respects may be regarded as the most important genus of the Potomac formation. It is a living genus, but is represented by only a single species, *T. elegans* Kunze, which is confined to the island of Juan Fernandez. It is closely related to Cyathea, and somewhat less closely to Dicksonia. In studying the extensive material from the Jurassic of Siberia, Professor Heer encountered a large number of specimens which he was unable to refer to any of the previously described fossil genera, and upon a very careful examination he found these forms to agree so exactly with the living genus Thyrsopteris that he was compelled to refer them to that genus. Brongniart had already pointed out the resemblance of his *Pecopteris Murrayana* from the Oolite of Yorkshire to this living genus, and had united this species with others into a distinct genus, Coniopteris, to which Saporta afterwards referred a number of species from the Jurassic of France. It is therefore very probable that the genus Thyrsopteris, which is now so nearly extinct, was widely distributed over the northern hemisphere in Jurassic time. We have in America no true Jurassic flora thus far, but should such a flora hereafter come to light there can scarcely be any doubt that this genus will be found in it. At all events, the most abundant type of fern that exists in our Older Potomac flora is so closely related to the Jurassic forms classed as Thyrsopteris that it was impossible for Professor Fontaine to separate them. Out of the great mass of material of this class collected by him, chiefly in the James River and Rappahannock series, he distinguished no less than 40 species. There may be grave doubts as to whether so large a number of species should have been made, but the characters are tolerably distinct, and should it be necessary in the future to combine some of these this will be much easier than it would be to separate species that had been injudiciously united. Of these 40 species 12 occur in the Aquia Creek series, only 1 of which, *T. distans* Font., is confined to that horizon, all the rest occurring in the Older Potomac also. Four species have been detected in the Mount Vernon Clays, but none of them is confined to these beds. Three of these species, *T. bella* Font., *T. decurrens* Font., and *T. rarinervis* Font., are found in all four of the Older Potomac series. Taking out all these cases there remain 27 species of Thyrsopteris which are confined to the Basal Potomac. Eight of these occur in both of the Basal members, 2 are confined to the James River, and 17 to the Rappahannock series.

The most important cycadaceous genera are Dioonites, Podozamites, Williamsonia, and Zamites. These, with the exception of the Podozamites, are all confined to the Older, and chiefly to the Basal, Potomac. The *Dioonites Buchianus* (Ett.) Born. is important, mainly, for its great abundance in the lowest beds known. It seems to have gradually grown rarer before the close of the James River period, and is a somewhat rare plant in the Rappahannock series. Its occurrence even in the Aquia Creek series is doubtful. It and its varieties are characteristic James River forms in the sense that they are almost always found wherever there are any plants at that horizon, while at any higher level they are to be met with only when the collections are large. The genus Podozamites is the largest of the Cycadaceæ, being represented by 12 species. Five are Basal Potomac species, 2 of which, however, pass up into the Aquia Creek series. In the Newer Potomac a number of forms have been found which must be referred for the present to that genus. They consist entirely of fragments of leaves too imperfect in most cases for safe specific determination. One has been referred to *P. tenuinervis* Heer, and another to *P. marginatus* Heer. The Mount Vernon Clays contain some well-preserved leaves of Podozamites. To the genus Williamsonia 6 forms have been referred, to only 4 of which specific names have been given. One of these, *W. virginiensis* Font., is confined to the James River beds, where it is not rare. The other 3 are confined to the Amboy Clays, and 1 of them is the plant that Dr. Newberry at first supposed to be a fossil sunflower and named *Palæanthus problematicus*. One of the undescribed forms was collected by Mr. White at Gay Head, and the other is from Alabama. I shall, for the present at least, treat this type as cycadean. To the genus Zamites belong 7 distinct forms, all from the Older Potomac, and none of them found in the Aquia Creek series. But in the Mount Vernon series *Z. crassinervis* Font. and *Z. tenuinervis* Font. have both been detected, and there is another well-preserved leaf that does not belong to either of these species. I have already dwelt sufficiently upon the forms that I call *Zamia Washingtoniana* (see supra, p. 350, and Pl. II, Fig. 6). On the whole, then, the Cycadaceæ of the Potomac formation are found to be almost exclusively Older Potomac and chiefly Basal Potomac, while in this order we have the most characteristic species of the James River series, or oldest known Potomac beds. The cycadean trunks of Maryland, referable to the genus Cycadeoidea, and of which a large number of specimens have recently been collected by Mr. Arthur Bibbins, probably belong with the leaves of one or other of the above-mentioned genera.

The Coniferæ, with their 146 species, constitute a very important group of plants for the Potomac formation. The largest genera are: Athrotaxopsis 6 species, Baieropsis 10 species, Brachyphyllum 8 species, Glyptostrobus 8 species, Leptostrobus 7 species, Nageiopsis 14 species, Pinus 9 species, Sequoia 22 species, and Sphenolepidium 8 species. The most interesting of these is Professor Fontaine's new genus Nageiopsis, so closely resembling a cycad, but which he regards as nearly related to the section Nageia of the living genus Podocarpus. This genus is exclusively confined to the Older Potomac. It is well represented in the James River series, but has 4 species that pass up into the Aquia Creek series. Two of these, *N. angustifolia* Font. and *N. longifolia* Font., are found in the intermediate Mount Vernon Clays. The genus may perhaps be regarded as having its highest development in the Rappahannock series. The genus Sequoia, though the largest of Potomac conifers, is so widely distributed throughout all the Cretaceous and Tertiary deposits over nearly the whole globe, still persisting on the Pacific Coast in 2 species, that its value as a genus is not specially important. In fact, it is one of the few genera which occur in every one of the 6 subdivisions of the Potomac formation here made, and one species, *S. Reichenbachi* (Gein.) Heer, is found in all of them except the Mount Vernon Clays. The great quantity of silicified wood found especially in the Rappahannock sands and referred to Cupressinoxylon really belongs without doubt to the genus Sequoia, and the trees that were thus petrified probably bore the leaves and cones of several of the species of that genus that are enumerated. Sphenolepidium is an exclusively Older Potomac genus, but 4 of its 8 species occur in the Aquia Creek series, though none of them are confined to it. It may be regarded as mainly a Rappahannock type.

Just as the ferns and cycads are chiefly confined to the Older Potomac, so the dicotyledons are in the main represented in the Newer Potomac. Still, there are a number of genera somewhat abundant in the Rappahannock, and found even in the James River series, whose leaves exhibit a peculiar nervation, which I have characterized as archaic.[1] Such are

[1] Am. Jour. Sci., 3d ser., Vol. XXXVI, August, 1888, p. 120.

the Aristolochiæphyllum, Ficophyllum, Proteæphyllum, Quercophyllum, Rogersia, Saliciphyllum, and Vitiphyllum. Celastrophyllum enjoys the distinction of being represented throughout the entire Potomac formation, being found in all its plant-bearing subdivisions, and it also has a special value as indicating a gradual transition in its varied forms from the lowest to the highest beds. Professor Fontaine's Rogersia seems without doubt to be the Older Potomac representative and true lineal ancestor of the forms which Dr. Newberry refers to Eucalyptus, and taking these two together we have almost as complete a series as that which Celastrophyllum presents. A somewhat shorter series may also be made out by combining the Sapindopsis of Fontaine, which begins in the Rappahannock series, with the Fontainea of Newberry from the lowest Raritan beds of Woodbridge, N. J., also found at Round Bay, on the Severn River, Maryland. Many other similar lines of development might even now be traced, but when all the material of this class is carefully elaborated, this branch of the investigation will become an exceedingly hopeful one.

The following table will show the numerical relations that subsist among the different types of vegetation represented in the Potomac flora:

Types of vegetation.	Genera.	Species.	Species to a genus.	Per cent of genera.	Per cent of species.
Cellular Cryptogams	2	2	1	1	.3
Ferns	31	160	5.2	15.7	21.7
Equisetaceæ	1	7	7	.5	.9
Cycadaceæ	14	44	3.1	7.1	6
Coniferæ	34	146	4.3	17.2	19.8
Casuarinaceæ	1	1	1	.5	.1
Monocotyledons	8	8	1	4	1
Dicotyledons	92	330	3.6	46.7	44.8
Of unknown affinities	15	39	2.6	7.6	5.3
Total	198	737	3.7		

GEOGRAPHICAL AND GEOLOGICAL DISTRIBUTION OF THE POTOMAC FLORA.

Thus far attention has been restricted entirely to the internal relations of the Potomac flora with a view to the correlation by means of fossil plants of the several subordinate floras or florulas corresponding to the stratigraphical subdivisions treated in the first part of this paper. It is now proposed to consider briefly the external relations of the Potomac flora, that is to say, the geographical and geological range that it has outside of the Potomac terrane.

It was seen in discussing the internal relations that of the 737 species which make up the Potomac flora only 140 occur at more than one of the six horizons into which the formation was divided. Similarly, in discussing the external relations we now find that only 176 species have a distribution outside of the Potomac formation proper. These may be divided into two distinct classes:

First, species that were named from other parts of the world before investigations into the Potomac formation had been instituted, chiefly at horizons not widely differing from some of those of the Potomac, and which have subsequently been discovered in the Potomac formation. Of such species 141 are enumerated.

Second, species that were first described and named from the Potomac formation and have since been found at other localities. Of species belonging to this class 35 have thus far occurred. It so happens that these latter are all species named by Professor Fontaine from the Older Potomac and have been found, chiefly by him, in collections from other Lower Cretaceous deposits in the United States.

These two classes will be considered separately in the order named.

DISTRIBUTION OF FOREIGN SPECIES.

As a basis for such remarks as it may be thought best to make upon the plants of this class, the following table of distribution of the 142 species representing it may best be introduced at this point:

Table of distribution of the species of fossil plants identified in the Potomac formation but previously described from other localities and horizons.

Species.	Potomac formation.						Other localities and horizons.																										
								Lower Cretaceous.									Upper Cretaceous.											Tertiary.					
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.	Jurassic.	Wealden.	Trinity.	Black Hills.	Kootanie.	Shasta.	Cape Lisburn, Alaska.	Neocomian, Europe.	Urgonian, Kome, Greenland.	Gault, Europe and Spitzbergen.	Atane beds, Greenland.	Dakota formation.	Upper Kanab Valley.	Mill Creek series, Canada.	Cenomanian, Europe.	Patoot, Greenland.	Canada and British Columbia.	Senonian, Europe.	Laramie formation.	Post Laramie (Denver, etc.).	Fort Union.	Arctic Tertiary (Eocene?).	Green River group.	Paleocene (Sézanne, Gelinden).	Eocene, Europe.	Oligocene, Europe.	Miocene, Europe.
Andromeda Parlatorii Heer						+											+	+															
Pfaffiana Heer						+											+	+															
Aralia formosa Heer						+												+			+												
grönlandica Heer						+											+	+															
quinquepartita Lx						+												+															
transversinervia Sap. & Mar						+																								+	+		
Wellingtoniana Lx						+												+															
Aristolochites dentatus Heer			?															+															
Aspidium Dunkeri (Schimp.) Font	+	+						+				?		+																			
Oerstedi Heer	+												+				+					+											
Asplenium Dicksonianum Heer					+	+				+	+		+		+		+	+															
Foersteri Deb. & Ett						+											+				+			+									
Baiera longifolia (Pom.) Heer	+						+				+																						
Brachyphyllum crassum Lx						+												+	+														
Celastrophyllum Benedeni Sap. & Mar						+																								+			
crenatum Heer					+	+																+											
cretaceum Lx						+												+															
decurrens Lx						?												+															
obtusum Heer						?											+																
Celastrus arctica Heer						+																+											
Chondrophyllum orbiculatum Heer						+											+																
Cinnamomum Heerii Lx						+												+					+										
Marioni Lx						?												+															
sezannense Wat						+											+					+								+	+		
Cissites crispus Vel						+															+												
formosus Heer						+											+	+															
Colutea primordialis Heer						+											+	+															
Cratægus subtilis Heer						?																						+					
Cunninghamites elegans (Corda) Endl						+		+													+	+		+									

Table of distribution of the species of fossil plants identified in the Potomac formation, etc.—Continued.

Species.	Potomac formation.						Other localities and horizons.																										
								Lower Cretaceous.								Upper Cretaceous.											Tertiary.						
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.	Jurassic.	Wealden.	Trinity.	Black Hills.	Kootanie.	Shasta.	Cape Lisburn, Alaska.	Neocomian, Europe.	Urgonian, Kome, Greenland.	Gault, Europe and Spitzbergen.	Atane beds, Greenland.	Dakota formation.	Upper Kanab Valley.	Mill Creek series, Canada.	Cenomanian, Europe.	Patoot, Greenland.	Canada and British Columbia.	Senonian, Europe.	Laramie formation.	Post Laramie (Denver, etc.).	Fort Union.	Arctic Tertiary (Eocene?).	Green River group.	Paleocene (Sézanne, Gelinden).	Eocene, Europe.	Oligocene, Europe.	Miocene, Europe.
Cyathea fertilis Heer						?											+																
Dalbergia hyperborea Heer						+											+																
Rinkiana Heer						+											+																
Dammara borealis Heer						+											+				+												
microlepis Heer						+											+																
Daphnophyllum dakotense Lx						?												+															
Dewalquea grönlandica Heer						+											+					+											
haldemiana (Deb.) Sap. & Mar						?													+			+		+									
insignis Hos. & Marck						+											+					+		+									
Dioonites Buchianus (Ett.) Born	+	+		?				+	+																								
Diospyros primæva Heer						+											+	+			+	+											
rotundifolia Lx						+												+															
Steenstrupi Heer						+																+											
Equisetum Lyelli Mant	+	+						+																									
Eucalyptus Geinitzi Heer						+											+	+			+												
Eugenia primæva Lx						?												+															
Ficus atavina Heer						+											+		+			+											
inæqualis Lx						+												+															
lanceolata Heer						?																			+	+			+		+		+
lanceolato-acuminata Ett						+												+														+	
protogæa Heer						?											+							+									
Frenelopsis Hoheneggeri (Ett.) Schenk						?	+	+	+						+																		
Geinitzia formosa Heer						?															+												
Gleichenia Giesekiana Heer						?									+		+					+											
gracilis Heer						+									+		+				+												
micromera Heer						+									+																		
Nordenskiöldi Heer	+	+	+												+			+															
Zippei (Corda) Heer						+				+					+	+	+				+	+		+									
Grewiopsis viburnifolia Ward						?																					+						
Hedera primordialis Sap						+											+				+												
Hymenæa Dakotana Lx						+												+															
Ilex Masoni Lx						+												+															

Table of distribution of the species of fossil plants identified in the Potomac formation, etc.—Continued.

Species.	Potomac formation.						Other localities and horizons.																										
								Lower Cretaceous.									Upper Cretaceous.											Tertiary.					
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.	Jurassic.	Wealden.	Trinity.	Black Hills.	Kootanie.	Shasta.	Cape Lisburn, Alaska.	Neocomian, Europe.	Urgonian, Kome, Greenland.	Gault, Europe and Spitzbergen.	Atane beds, Greenland.	Dakota formation.	Upper Kanab Valley.	Mill Creek series, Canada.	Cenomanian, Europe.	Patoot, Greenland.	Canada and British Columbia.	Senonian, Europe.	Laramie formation.	Post Laramie (Denver, etc.).	Fort Union.	Arctic Tertiary (Eocene?).	Green River group.	Paleocene (Sézanne, Gelinden).	Eocene, Europe.	Oligocene, Europe.	Miocene, Europe.
Juglans arctica Heer						?											+	+															
crassipes Heer						+												+			+	+											
Juniperus hypnoides Heer						+											+								+								
macilenta Heer					?	+											+				+												
Laurophyllum ellsworthianum Lx						?												+															
Laurus Hollæ Heer						?											+	+				+											
Omalii Sap. & Mar.						+																								+			
plutonia Heer						+											+	+			+	+											
præstans Lx						?																			+								
Leguminosites atanensis Heer						+											+																
constrictus Lx						?												+															
convolutus Lx						?												+															
frigidus Heer						+																+											
omphalobioides Lx						+												+															
Magnolia alternans Heer						+											+	+			+				+								
Capellinii Heer						+											+	+			+												
Isbergiana Heer						+											+																
Lacoeana Lx						?												+															
speciosa Heer						+												+			+												
Majanthemophyllum pusillum Heer						+																+											
Menispermites borealis Heer						+											+																
Microzamia gibba (Reuss) Corda						+															+			+									
Moriconia cyclotoxon Deb. & Ett						+											+					+		+									
Myrica emarginata Heer						+											+	+															
longa Heer						?											+	+			+	+	+										
parvula Heer						+																+											
Myrsine borealis Heer					+	+											+																
Nyssa Snowiana Lx						?												+															
Ophioglossum granulatum Heer						+																+											
Osmunda Obergiana Heer						+											+																
Paliurus affinis Heer						?																+											
ovalis Dn						+												+		+													

Table of distribution of the species of fossil plants identified in the Potomac formation, etc.—Continued.

Species.	Potomac formation.						Other localities and horizons.																										
								Lower Cretaceous.									Upper Cretaceous.											Tertiary.					
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.	Jurassic.	Wealden.	Trinity.	Black Hills.	Kootanie.	Shasta.	Cape Lisburn, Alaska.	Neocomian, Europe.	Urgonian, Kome, Greenland.	Gault, Europe and Spitzbergen.	Atane beds, Greenland.	Dakota formation.	Upper Kanab Valley.	Mill Creek series, Canada.	Cenomanian, Europe.	Patoot, Greenland	Canada and British Columbia.	Senonian, Europe.	Laramie formation.	Post Laramie (Denver, etc.).	Fort Union.	Arctic Tertiary (Eocene?).	Green River group.	Paleocene (Sézanne, Gelinden).	Eocene, Europe.	Oligocene, Europe.	Miocene, Europe.
Pecopteris Browniana Dunk	+	+		?			+	+			+			+																			
socialis Heer				+													+																
Persea nebrascensis Lx						+												+															
Phegopteris Grotheana Heer						?																+											
Phyllites amissus Lx						?												+															
durescens Lx						?												+															
Vanonæ Heer						?												+															
Platanus Heerii Lx						+											+	+		+													
Newberryana Heer						+												+				+											
Podozamites angustifolius (Eichw.) Schimp						+	+											+															
marginatus Heer			?			?											+																
tenuinervis Heer						+											+																
Populites elegans Lx						?												+															
Populus hyperborea Heer						?											+	+															
Proteoides daphnogenoides Heer					+	+												+		+													
Protophyllum præstans Lx					?													+															
undulatum Lx					?													+															
Pterospermites longeacuminatus Lx						?												+															
modestus Lx						+												+															
Quercus Johnstrupi Heer						+																+											
Rhamnus inæquilateralis Lx						?												+															
Pfaffiana Heer						+																+											
Salix proteæfolia Lx						+												+															
flexuosa Lx						?												+															
Raeana Heer						?																			+			+					+
Sapindus Morrisoni Lx						+											+	+				+											
Sapotacites retusus Heer						+																+											
Sassafras acutilobum Lx					+	+												+			+												
Sequoia ambigua Heer	+				?										+		+																
condita Lx						+												+															
gracillima (Lx.) Newb					+	+												+		+			+										
gracilis Heer				+							+				+																		

Table of distribution of the species of fossil plants identified in the Potomac formation, etc.—Continued.

Species.	Potomac formation.						Other localities and horizons.																										
								Lower Cretaceous.									Upper Cretaceous.											Tertiary.					
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Upper Albirupean.	Jurassic.	Wealden.	Trinity.	Black Hills.	Kootanie.	Shasta.	Cape Lisburn, Alaska.	Neocomian, Europe.	Urgonian, Kome, Greenland.	Gault, Europe and Spitzbergen.	Atane beds, Greenland.	Dakota formation.	Upper Kanab Valley.	Mill Creek series, Canada.	Cenomanian, Europe.	Patoot, Greenland.	Canada and British Columbia.	Senonian, Europe.	Laramie formation.	Post Laramie (Denver, etc.).	Fort Union.	Arctic Tertiary (Eocene?).	Green River group.	Paleocene (Sézanne, Gelinden).	Eocene, Europe.	Oligocene, Europe.	Miocene, Europe.
Sequoia heterophylla Vel.					+	+															+			+									
Reichenbachi (Germ.) Heer	+	+		+	+	+	+				+				+	+	+	+			+		+	+	+								
rigida Heer	+	+				+					+				+	+	+				+	+		+									
Smittiana Heer						+					+				+								+										
subulata Heer	+	+			+	+											+																
Sphenolepidium Kurrianum (Dunk.) Hr.	+			+			+	+						+																			
Sternbergianum (Dunk.) Heer		+	+				+	+						+																			
Sphenopteris grevillioides Heer			+			+									+																		
Mantelli Brongn.				?			+	+				+		+							+												
Sterculia Snowii Lx.						?												+															
Thinnfeldia Lesquereuxiana Heer						+											+																
Thuya cretacea (Heer) Newb.						+											+																
Thuyites Meriani Heer						+									+		+																
Viburnum inæquilaterale Lx.						+												+															
Widdringtonites Reichii (Ett.) Heer						+											+				+	+											
subtilis Heer						+											+																

It will be seen from this table that although there are species which have a foreign distribution, in the sense explained, from each of the six subdivisions of the Potomac formation, the great bulk of them belong to the Newer Potomac, and chiefly, of course, to the Amboy Clay flora. It will also be observed, in harmony with the last remark, that although in such foreign distribution there is a range extending from the Jurassic to the Miocene, still, by far the greater part of the species thus compared were originally described from the Cretaceous, and especially from the Middle Cretaceous. The particular group that has yielded the largest number of such species is that known as the Atane beds of Greenland, correlated by Heer and other authors with the Cenomanian of Europe. Next to this comes the Patoot beds of Greenland, occupying a higher horizon, and correlated by common consent with the Senonian of Europe.

The whole number of species common to the Potomac and the Atane beds is 56, 10 of which, however, have their identity somewhat in doubt, as indicated by the query mark in the Potomac column. Most of these cases are probably correct, and where they do not exactly correspond they no doubt indicate a close genetic relationship. On the general theory that the Lower Cretaceous once extended around the entire Atlantic border, but that north of Massachusetts the sea has encroached upon it so as to cut it away entirely, its recurrence in Greenland, in the position of the Kome and Atane beds, is a perfectly natural circumstance. The channel which separates Greenland from the next land to the west has in like manner cut away the older portion of the formation, and left for the most part only the later Cretaceous deposits. These were probably also present in some parts of the United States, where they are now buried deeply beneath still later marine deposits. The Kome beds of Greenland, however, actually represent a horizon corresponding to the Older Potomac, and, as will be seen by this table, they contain a number of species which have been identified in the latter. It is not absolutely impossible, either, that the highest beds of the Newer Potomac, as for example those of Long Island and Gay Head, may be nearly or quite as high as the Atane beds themselves, and it is doubtful whether there is sufficient evidence outside of the fossil plants to prove that the Atane beds are properly to be classed in the Upper rather than in the Lower Cretaceous. Be this as it may, the 46 well-authenticated species that are common to the two have a strong bearing as establishing their close geological synchronism. Nor is it to be wondered at that a considerable number of species should be common to the Newer Potomac and the Patoot beds. There are 31 such species, but the greater part of them also occur in the Atane beds; that is, they are species which have passed up from the Lower into the Upper Cretaceous in the same restricted geographical position.

Quite a large number of these species, about 25, were originally found in the Middle Cretaceous or Cenomanian of Europe, and have been identified with more or less certainty in the Newer Potomac. A considerable number of these are also common to the Atane beds, and some have a wide distribution.

The most important fact brought out in this table, and the one which most needs to be commented upon and explained, as liable to lead to erroneous conclusions, is the very large number of species that would seem upon the face to be common to the Newer Potomac and the Dakota formation. There are no less than 66 such cases, or 10 more than were noted for the Atane beds. No better illustration could be found of the imperfection of such tabular statements for setting forth the true state of things under such conditions as we have before us. A very little analysis will show how entirely deceptive this fact is. For example, a casual glance at the table shows that of these Dakota species 19 are also common to the Atane beds. They are species described by Heer and afterwards identified by Lesquereux as also occurring in the Dakota. As is now well known, many of these identifications will require revision. In most cases there are differences enough to indicate that considerable change at least had taken place in the species before their reappearance in Dakota time, and in several cases this difference is doubtless specific. But even if we were to admit that the identifications were all correct, it would still not be true in any of these 19 cases that properly Dakota species had been found in the Amboy Clays, but only that so many Atane species are found in both the Amboy Clays and in the Dakota group.

If now we glance at the Newer Potomac columns we find that still another 19 species are introduced into those columns with marks of interrogation, which means that Dr. Newberry and Dr. Hollick were in doubt as to their identification with Dakota species. A few of these cases will doubtless stand, but in most of them, when additional material shall have been collected, it will probably be found that they are only more or less closely related to the Western forms. There are several other cases of such wide distribution as to have no significance from this point of view. When, therefore, we sift the matter to its essential elements, we find that there are really only 18 bona fide cases in which Dakota species have been identified in the Amboy Clays or their equivalent. These 18 species are the following:

Aralia quinquepartita Lx.
Wellingtoniana Lx.
Brachyphyllum crassum Lx.
Celastrophyllum cretaceum Lx.
Cinnamomum Heerii Lx.
Diospyros rotundifolia Lx.
Ficus inæqualis Lx.
Hymenæa dakotana Lx.
Ilex Masoni Lx.
Leguminosites omphalobioides Lx.
Persea nebrascensis Lx.
Proteoides daphnogenoides Heer.
Pterospermites modestus Lx.
Salix proteæfolia Lx.
Sassafras acutilobum Lx.
Sequoia condita Lx.
gracilis (Lx.) Newb.
Viburnum inæquilaterale Lx.

All but 4 of these 18 species are, so far as now known, confined to the Dakota group and the Newer Potomac. *Brachyphyllum crassum* Lx. was first described from the Upper Kanab Valley in Utah, where a considerable collection was once made, but the age of which has never been definitely fixed. In it Professor Lesquereux also identified the *Dewalquea haldemiana* (Deb.) Sap. and Mar., a plant from the Senonian of Europe which recurs in the Patoot beds of Greenland, and *Ficus atavina* Heer from the Atane and Patoot beds. *Cinnamomum Heerii* Lx. is believed to have been found in the Nanaimo beds on Vancouver Island, also on Orcas Island, both of which are regarded as Upper Cretaceous. Its supposed occurrence at the locality on Bellingham Bay is one of the facts which put the horizon of that locality in doubt. *Proteoides daphnogenoides* Heer has been detected by Dawson in the Mill Creek series of Canada. *Sassafras acutilobum* Lx., the only other species that has a distribution outside of the Dakota formation and Amboy Clays, is one of the best-known Dakota species, and has been identified by Velenovský in the Cenomanian of Bohemia at Kuchelbad. It is one of the forms which I am tolerably sure I have found on Pennsylvania avenue extended, District of Columbia, and also at Brightseat, Md.

I have gone into these details with regard to the Dakota species found in the Amboy Clays on account of the important bearing that they have upon the correlation of the Potomac flora. Of these 18 species there is probably no doubt whatever, and they would seem to argue for a considerable resemblance between the two floras, but when we remember that the Newer Potomac flora aggregates 347, and that of the Dakota group 460 species, it will be seen that the number of species common to the two is after all not very large. The resemblance is somewhat heightened, however, by the number of other forms provisionally identified in the two formations, which, even if they do not represent identical species, do represent in the main closely related ones. All this is what we ought to expect in comparing the plants that grew on one and the same great continental area, not only within the limits of the Cretaceous system, but during the earlier two-thirds of the period embraced in the Cretaceous epoch. It has been said that the chief difficulty in determining age by means of fossil plants is that these are so long lived. It must be admitted that this objection holds for formations which are closely related geologically, but it only argues for greater caution against generalizing from limited material, as explained by my second "principle."[1] For such restricted periods abundant collections are necessary. This objection applies with still greater force to many animal remains, some of which, such as Lingula,

[1] Principles and Methods of Geologic Correlation by Means of Fossil Plants: American Geologist, Vol. IX, Minneapolis, January, 1892, p 37. Principes et Méthodes d'Étude de Corrélation Géologique au moyen des Plantes Fossiles; Congrès Géologique International, Compte-rendu de la 5me session (Washington meeting, 1891), Washington, 1893, p. 100.

for example, extend throughout the whole of Paleozoic, Mesozoic, and Cenozoic time, to the present. It also applies to all the animal remains found in the Potomac and Dakota formations, except the vertebrates. The Unios and other shells that are found in these fresh and brackish water deposits are absolutely without geologic value simply on account of the fact that the same species are liable to occur at any horizon.

DISTRIBUTION OF AMERICAN SPECIES.

The other class of Potomac plants that have a distribution outside of that formation, as restricted in this paper, consists, as already remarked, of 35 of the Older Potomac species of Professor Fontaine that have since been identified by him, by Dr. Newberry, or by Sir William Dawson in the Trinity group of Texas, the Kootanie of Great Falls, Mont., and Canada, and in the Shasta group of California. The distribution of these species is shown in the following table:

Potomac species occurring at other localities and horizons.

Species.	Potomac formation.					Other Lower Cretaceous deposits.		
	James River.	Rappahannock.	Mount Vernon.	Aquia Creek.	Lower Albirupean.	Trinity.	Kootanie.	Shasta.
Abietites angusticarpus Font.	......	+	......	+	......	......	......	+
Angiopteridium nervosum Font.	......	+	......	......	......	......	......	?
strictinerve Font.	......	+	......	......	......	......	......	?
Aspidium fredericksburgense Font.	+	+	......	......	......	......	+	......
heterophyllum Font.	......	+	......	......	......	......	......	+
Aspleniopteris pinnatifida Font.	......	+	......	......	......	......	......	?
Carpolithus virginiensis Font.	+	......	......	......	......	......	+	......
Cephalotaxopsis magnifolia Font.	+	+	......	......	......	......	......	?
Cladophlebis constricta Font.	......	+	?	+	......	......	+	......
distans Font.	+	......	......	......	......	......	+	......
falcata Font.	......	+	......	......	......	......	+	......
inclinata Font.	+	......	......	......	......	......	......	?
parva Font.	......	+	......	......	+	......	+	......
Cycadeospermum rotundatum Font.	+	......	......	......	......	+	?	......
Dioonites Buchianus angustifolius Font.	+	......	......	......	......	+	......	+
Equisetum marylandicum Font.	......	+	......	+	......	......	?	......
Laricopsis longifolia Font.	+	......	......	......	......	+	......	......
Leptostrobus longifolius Font.	+	+	......	+	......	......	+	......
Nageiopsis longifolius Font.	+	+	+	+	......	......	......	+
Osmunda dicksonioides Font.	......	+	......	......	......	......	+	?
Pecopteris microdonta Font.	+	+	......	......	......	......	+	......
strictinervis Font.	......	+	......	?	......	......	......	?
Podozamites acutifolius Font.	+	+	......	+	......	?	......	......
distantinervis Font.	+	+	......	?	......	......	?	......
Sagenopteris latifolia Font.	+	......	......	......	......	......	......	?
Sphenolepidium pachyphyllum Font.	+	......	......	......	......	......	?	......
Sternbergianum densifolium Font.	+	+	......	+	......	+	......	......
virginicum Font.	......	+	......	+	......	......	+	......
Sphenopteris latiloba Font.	+	+	?	+	......	......	+	......
Thinnfeldia variabilis Font.	......	+	......	+	......	......	......	?
Thyrsopteris brevifolia Font.	+	......	+	......	......	......	+	......
brevipennis Font.	+	......	......	+	......	......	+	......
insignis Font.	......	+	......	......	......	......	+	......
microloba alata Font.	+	+	......	......	......	......	?	......
rarinervis Font.	+	+	+	+	......	......	+	?
Zamites tenuinervis Font.	+	+	+	......	......	+	......	......

Scarcely anything need be said in explanation of this table. Six of the species occur in the Trinity division of the Comanche series of

Texas; 20 of them in the Kootanie group, which includes the Canadian deposits as well as the one at Great Falls, Mont.; and 14 in the Horsetown and Knoxville beds belonging to the Shasta group of California. *Cycadeospermum rotundatum* Font., a James River species, occurs in both the Trinity and the Kootanie, *Dioonites Buchianus angustifolius* Font. in the Trinity and the Shasta, *Osmunda dicksonioides* Font. and *Thyrsopteris rarinervis* Font. in the Kootanie and the Shasta. The last is found in all the Older Potomac beds.

In a considerable number of cases, especially in the Shasta collections, Professor Fontaine has not been willing to express himself positively as to specific identity, and in such cases I have introduced the mark of interrogation. As the floras of these different beds become better developed these doubts will of course disappear, and it is altogether probable that a much larger number of species will be found common to them and to the Potomac flora.

Extra-limital species.—In connection with the subject last discussed the fact may be stated here, to be brought out more fully in a subsequent paper, that from the Lower Cretaceous deposits already mentioned and from several others in America not represented in the last table, 81 species have thus far been described which are not found in the Potomac formation. A few of them are Old World Jurassic and Wealden plants, and some are from the Kome beds of Greenland, but the greater number are new species with a strong Wealden and Jurassic facies. It therefore seems probable that the Lower Cretaceous plant-bearing deposits of Texas, South Dakota, Montana, California, the Queen Charlotte Islands, and Cape Lisburn, Alaska, all belong to that portion of the Cretaceous which is best represented by the Older Potomac at least, and perhaps by the Basal Potomac.

SKETCH OF THE GEOLOGY OF THE SAN FRANCISCO PENINSULA.

BY

ANDREW C. LAWSON.

CONTENTS.

ILLUSTRATIONS.

SKETCH OF THE GEOLOGY OF THE SAN FRANCISCO PENINSULA.

By Andrew C. Lawson.

INTRODUCTION.

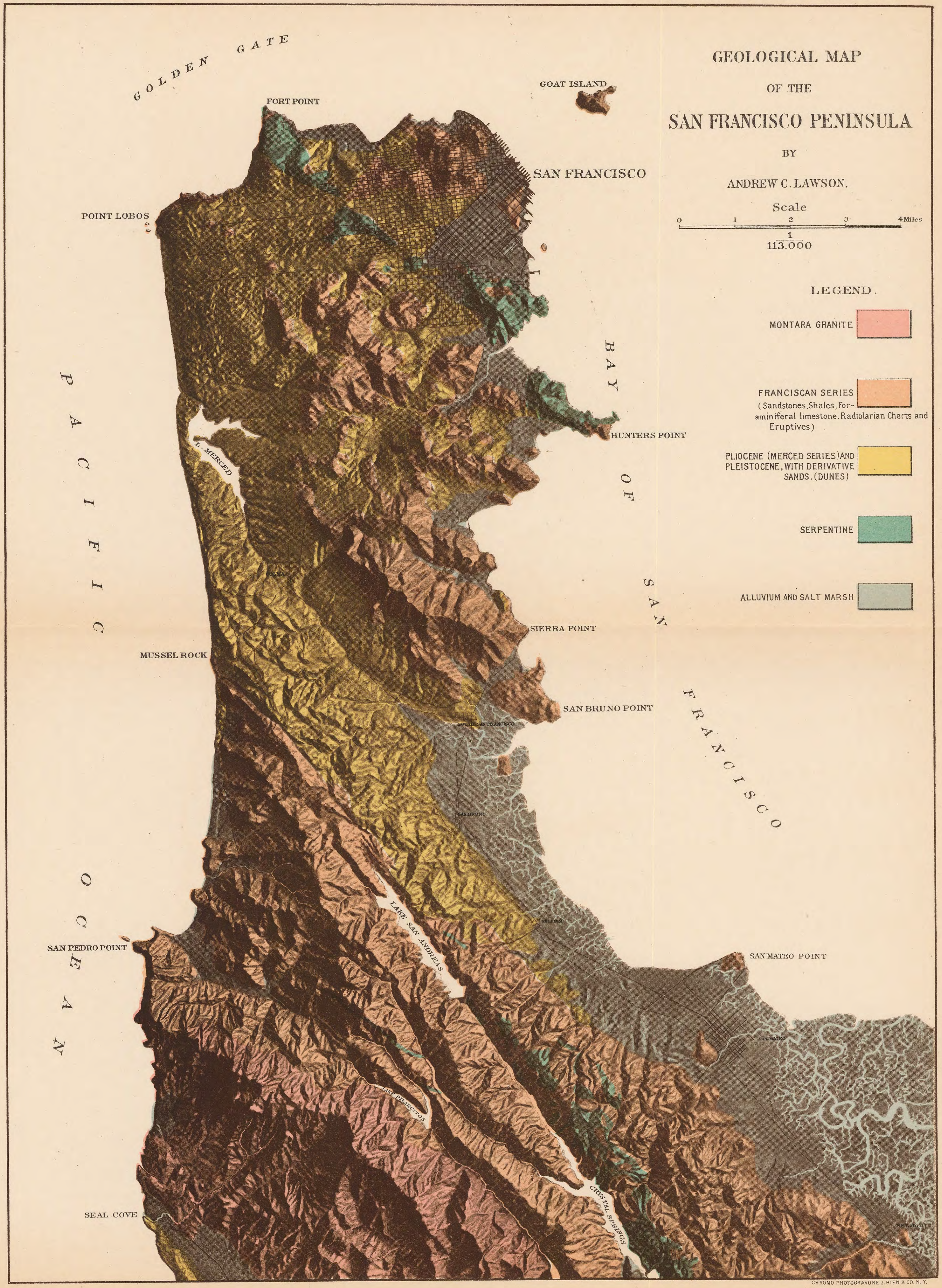
Up to the present decade our knowledge of the geology of the Coast Ranges of California has been extremely limited and unsatisfactory. Not a few geologists have written upon the subject, but some of these have labored under the disadvantage of having for their theme the geology of the Coast Ranges in general, and of being without a detailed knowledge of any single portion of the ranges sufficiently large and representative to serve as a basis for generalization. Errors and impossible hypotheses have thus crept into the literature. Other writers, particularly those connected with the Pacific Railway surveys, have, in a more conservative spirit, simply recorded their reconnaissance observations without extended comment. These notes are among the most valuable contributions to the literature of the subject. Owing to their disconnected character, however, they have not been fruitful of more than a wholesome and as yet unsatisfied curiosity regarding these remarkable mountains. Of the various departments of geology concerned in the elucidation of the Coast Ranges, paleontology has certainly made most headway, thanks to the energetic efforts of Gabb under the old geological survey of the State. Other departments of geology have been singularly ineffective, and perhaps it is as well that such is the case. The curious views on questions of metamorphism, so apparent in the older writings, were leading to hopeless confusion, and it is not an evil that the literature imbued with such ideas is of moderate dimensions. It is perhaps a gain to science that the problems of the Coast Ranges yet remain to be attacked with the full momentum of modern methods and in the light of modern discovery.

Within the present decade a marked improvement is manifest in the literature of Coast Range geology. The spirit of generalization is not less active than in the earlier writings, but it is more efficiently checked by a keen realization of the necessity of having thorough and exact local knowledge as the only basis upon which generalizations may be built. It is evident that investigation is now proceeding by sure, if slow, steps, and that the progress of our knowledge will be marked by the number of distinct localities or distinct problems which shall be subjected to rigid methods of scientific inquiry.

The inquiry of which the chief results are given in this paper is intended as a contribution to the geology of the Coast Ranges. The region covered is of small extent, but its investigation has been undertaken in the conviction that thorough local study is more productive of useful and lasting results than skirmishing observations throughout the length of the ranges. The discussion is not intended to be exhaustive and is, therefore, not a final statement of the geology of the San Francisco Peninsula. The field is difficult, and exceedingly complex in detail. Many questions have arisen which are not mentioned in the discussion, and some conclusions are reached, particularly in the consideration of the diastrophism and the geomorphic development of the field, which must be regarded as of the nature of hypotheses, put forward that they may be improved, or even remodeled, by future criticism. They represent the writer's interpretation of the facts, and to the writer the chief interest in this field centers about these questions as perhaps the most important for a general comprehension of the history of the Coast Ranges. It is eminently desirable that errors of judgment should be eliminated from these hypotheses so that they may represent fair inferences from the facts, and friendly criticism from those who enjoy the advantage of a distant view will therefore be welcomed as an important aid to future work.

The study of the geology of the peninsula has been possible only by the use of good maps. For the first time the method of systematic mapping has been applied to the study of the Coast Ranges, and the results have strengthened the writer's conviction that this is the only effective method of arriving at clear conceptions of their general geology. The topographic atlas sheets of the Survey, constructed by Mr. R. B. Marshall, on a scale of 2 inches to the mile, have been all that could be desired. Indeed, so excellent are these maps in every detail, and so entirely free from errors, that they can not be too much praised. From these maps and from the Coast Survey chart of the northern portion of the peninsula a model of the entire field was constructed by the geological department of the University of California. This model has been of great service in the study of the field, and has been photographed and reproduced in Pl. V, upon which the several geologic formations are shown in colors, so that detailed descriptions of the areal distribution of the various geological formations will be dispensed with as far as possible.

During the progress of the field work the writer has been efficiently assisted by Messrs. Charles Palache and F. Leslie Ransome.


GEOLOGICAL MAP
OF THE
SAN FRANCISCO PENINSULA
BY
ANDREW C. LAWSON.
Scale
0 1 2 3 4 Miles
1/113.000
LEGEND.
MONTARA GRANITE
FRANCISCAN SERIES (Sandstones, Shales, Foraminiferal limestone. Radiolarian Cherts and Eruptives)
PLIOCENE (MERCED SERIES) AND PLEISTOCENE, WITH DERIVATIVE SANDS. (DUNES)
SERPENTINE
ALLUVIUM AND SALT MARSH
GOLDEN GATE
FORT POINT
GOAT ISLAND
SAN FRANCISCO
POINT LOBOS
BAY OF SAN FRANCISCO
HUNTERS POINT
L. MERCED
PACIFIC OCEAN
SIERRA POINT
MUSSEL ROCK
SAN BRUNO POINT
LAKE SAN ANDREAS
SAN PEDRO POINT
SAN MATEO POINT
LAKE PILARCITOS
CRYSTAL SPRINGS
SEAL COVE
CHROMO PHOTOGRAVURE J. BIEN & CO. N. Y.

GENERAL STATEMENT.

The investigation of the geology of the San Francisco Peninsula from about latitude 37° 30′ northward has revealed the existence of many sedimentary and igneous formations. The grouping of these in accordance with well-known geological principles reduces them to seven groups, which, by reason of the restricted technical sense attached to the word group, will be referred to as terranes. This term is used as a necessary word of variable significance, to designate any formation or group of formations in connection with its areal distribution. These seven terranes, in order of their geological age, are:

(1) Crystalline limestone, age unknown.

(2) Granite, referred to as "Montara granite," intrusive in the crystalline limestone.

(3) The Franciscan series, an assemblage of sedimentary and volcanic rocks of great thickness, with which are associated various basic intrusives, notably peridotite serpentines. This series rests upon the eroded surface of the Montara granite. It is of Mesozoic age, but enough is not yet known of its fossil fauna to permit of a more precise determination.

(4) A formation of light-colored, cavernous-weathering sandstone, which is supposed doubtfully to be of Tejon age.

(5) The Monterey series (Miocene), chiefly white, siliceous shale, practically devoid of detrital matter. This reposes upon the supposed Tejon, which in turn rests upon the Montara granite, thus demonstrating the local denudation of the Franciscan series from the granite prior to the Tertiary.

(6) The Merced series (Pliocene), a thick volume of sediments, with one stratum of volcanic ash, deposited after the erosion of the Miocene.

(7) The Terrace formations (Pleistocene and later), deposited after the disturbance and partial denudation of the Merced series.

Of these seven terranes the Montara granite, the Franciscan series, and the Merced series are the dominant features in the geology of the peninsula. All seven are important factors in the general geology of the Coast Ranges.

The consideration of the petrography, tectonic relations, and sculpture of these various terranes, both as a whole and as regards their constituent sedimentary and igneous formations, suggests many interesting problems. These problems relate to conditions of deposition, metamorphism, diastrophism, and geomorphogeny. The Montara granite introduces us to the still unsolved problem of the development of batholitic magmas. In the Franciscan series we have, in addition to the detrital rocks, foraminiferal limestones and great formations of very peculiarly bedded radiolarian cherts. The conditions governing the deposition of these rocks are not clear, but there are strong indications that they are essentially chemical deposits, although containing organic forms. In the same series certain rocks held by some earlier writers on Coast Range geology to be metamorphic sediments are shown to be true igneous rocks, chiefly contemporaneous volcanic extravasations. The serpentines, which have also been held to be metamorphic sediments, are shown to be altered peridotites or pyroxenites, which are intrusive formations in the Franciscan series in the form of dikes and laccolitic lenses. There are certain highly crystalline schists which form part of the series. These are shown to be altered forms of the normal sedimentary and volcanic rocks of the series. They are associated with the serpentines and with other irruptives, and the hypothesis is advanced that they represent contact zones of local metamorphism connected with the intrusive masses. The further hypothesis is advanced that none of the crystalline schists of the Coast Ranges are products of regional metamorphism, as that term is commonly understood, but that they are contact zones of irruptive masses, which in many cases are peridotites, now serpentinized.

Apart from the diastrophic disturbances, foldings, and uplifts which mark the time intervals between the different terranes, the field resolves itself, from an orogenic point of view, into two great fault blocks, each tilted to the northeast, with a structural valley between. The sculpture of these blocks during the very remarkable oscillations of the coast in post-Pliocene time, together with the development of certain minor constructional or block forms, yields us the geomorphy of the present time. The history of the diastrophic movements which have affected the field, and which have contributed to and been part of the process of the evolution of our modern geomorphy, is so astounding and so complex that no summary statement of it can be given till the reader is familiar with the leading features of the geology. Such statement is therefore deferred, and appears in the closing portion of the paper.

THE MONTARA GRANITE.

OCCURRENCE.

The granite which constitutes the mass of Montara Mountain is of very simple and definite dimensions within the limits of the field here considered. Going southward along the ocean shore of the peninsula, it is first seen at the base of the exceedingly abrupt and lofty sea-cliffs which form the terminal revetment of Montara, in the vicinity of San Pedro Point. The first outcrop is on the shore-line about 1 mile south of the point mentioned. Here the basal conglomerate of the Franciscan series rests upon the worn, sloping surface of the granite. From this point the trace of the plane of superposition of the conglomerate on the granite ascends the face of the cliff rapidly toward the south. About $1\frac{3}{8}$ miles south of San Pedro Point is a bold, cone-shaped projection from the cliff line called the Devil's Slide. The summit of the cone is 425 + feet above the shore and about 100 feet above the notch which separates it from the general upper face of the cliff. The line of junction of granite and conglomerate passes above this notch. The notch has been cut down through the conglomerate into the granite, leaving a northward-sloping sheet of conglomerate forming the summit and most of the northern face of the cone. This cap of conglomerate rests upon granite, which appears in precipitous cliffs around the base of the cone on the north side and reaches nearly to the summit on the south side. From this notch onward the cliffs in which the line of junction is traced face more to the south than to the west, and the latter, falling into the line of strike of the strata, undulates across the precipitous bluff in a nearly horizontal attitude for about half a mile. It intersects the coast road in a steep canyon at an elevation of 450 feet, where a sharp contact may be observed in a vertical wall of clean rock. Thus far the Franciscan strata repose on the granite basement in a gently tilted condition. At a distance of three-quarters of a mile east from the summit of the Devil's Slide an abrupt change in the attitude of the rocks is apparent, the northerly dip of the strata becoming strongly accentuated. In consequence of the change of dip, with which is associated a transverse fault of perhaps 300 feet, the line of junction of the two formations ascends the mountain side at the point indicated, and passing over a depression in the crest line of the ridge at 900 feet above the sea, crosses from the southern slope of the mountain to the northern. In passing eastward the conglomerate character of the base of the fragmental series becomes less pronounced, and it gives way to that of a coarse sandstone.

On the northern slope of Montara the sandstones reach well up on the flank of the mountain and, as stated, dip away from it at a moderately high angle. This attitude is uniform for several miles, and the upper limit of the sandstones against the granite slopes is traceable as a nearly straight line varying in altitude from 800 to 1,100 feet according as it crosses the canyons or the intervening shoulders of the mountain to the vicinity of the west end of the longer arm of Pilarcitos Lake. Here the line of junction bends toward the lake and comes within one-eighth of a mile of its shores, descending to an altitude of 725 feet. It then bends away from the lake, and, ascending the mountain side, crosses the road from Pilarcitos to the summit at an altitude of 1,300 feet. From this point it again descends till it reaches the bed of Pilarcitos Creek at a point about three-fourths of a mile below the dam. On Pilarcitos Lake, on the south end of the dam, there is a small inlier of granite, which emerges from beneath the sandstone and is entirely surrounded by the latter. Its area is crescent-shaped, concave toward the mountain, and the distance between the horns of the crescent does not exceed three-eighths of a mile. From the point where it descends to the creek bed in Pilarcitos Canyon the line of junction follows closely the bottom of the canyon for $2\frac{1}{2}$ miles. At this point the stream bends sharply toward the west, and the line of junction, continuing its former course, follows the crest of a ridge which separates the canyon of the Pilarcitos from a neighboring canyon which heads in a wind gap near the stage road to Halfmoon Bay.

Here the granite mass passes south of latitude 37° 30′, which forms the southern limit of the atlas sheets upon which the field observations were platted. (See Pl. V.) In the last mile of the line of junction, as thus traced, all the Franciscan rocks which adjoin the granite are not the sandstones of the basal portions of the series. About a mile or less from the southern end of the map a band of foraminiferal limestone abuts against the granite; and just below this a band of volcanic rock bears the same relation to the granite. Just where the line of junction crosses the limit of the map a formation of basic pyroclastic rocks also intervenes between the sandstones and the granite. Both the limestone and the volcanic rock belong, as will be shown later, to higher portions of the series, and clearly have been let down against the granite by a fault which will be discussed later.

From Pilarcitos Canyon to Halfmoon Bay, on latitude 37° 30′, only granite occurs. The mass does not, however, continue far southward with this breadth of outcrop. The edges of the overlying mantle of Franciscan and Tertiary strata converge rapidly from both sides of the ridge, and appear to close, so as definitely to limit the area of the granite, but a short distance south of the stage road. Indeed, the latter cuts through a belt of Tejon (?) and of Miocene rocks of the Monterey series which flanks the granite, with a strike approximately parallel to the southern limit of the map. At Halfmoon Bay the granite does not reach the shore, but is concealed by delta material and overlapping alluvial fans.

This alluvial deposit also occupies the lower ground to the north of Halfmoon Bay, and separates the granite from the low narrow ridge of Pliocene rocks which extends from Seal Cove to Pillar Point. North of Seal Cove, however, the direct superposition of the Pliocene strata upon the granite is very clearly exposed in an interesting cliff section. From Seal Cove northward the granite occupies the coast for 3½ miles to the place where we first encountered it below San Pedro Point. In this interval, however, there is a small alluvium-filled valley, where the alluvium forms the sea cliffs for about five-eighths of a mile.

We have thus traced the observed circuit of the confines of the Montara granite mass. When the observations recorded are platted upon the atlas sheet and an estimate is made of the extension beyond the limits of the latter, it is found that the terrane occupies an elliptical area, whose major axis is about 10 miles in a northwest and southeast direction, and whose minor axis, transverse to this and passing through Seal Cove, is about 4 miles. Practically no other formations exist within this area. Minute remnants of formations that were once more extensive have, however, been detected. These are (1) an included mass of crystalline marble in the granite, observed on the west side of Pilarcitos Canyon, a little more than half a mile north of the southern limit of the atlas sheet, at an altitude of between 500 and 700 feet; (2) occasional residual traces of gravel formations, reposing upon the shoulders of the mountains, which are the results of the dissection of wave-cut terraces; (3) about a dozen rounded, weathered bowlders of amygdaloidal basalt lying loose upon the granite surface of the summit of a hill on the south side of the creek which flows out at Montara Point. None of these exceeded 4 or 5 inches in diameter. They are evidently residuary bowlders of disintegration, the merest vanishing trace of a once extensive sheet.

With these exceptions, all other rock within the area above described is granite, and granite occurs nowhere else in our field.

PETROGRAPHY.

It is difficult to find anywhere an area of granite, of even a very few miles in extent, which is not traversed by dikes or veins of a later granite. Montara Mountain affords no exception to this rule. There are two granites, viz, that which constitutes the mass of the mountain, and that which cuts it in dikes. Neither of these granites is petrographically uniform throughout the extent of the mountain.

The Montara granite proper is in general a coarse, gray, hornblende-biotite granite. Under this general designation the mass presents many facies, apart from those variations due to secular decay. These facies depend for their characteristic features upon, first, the proportion in which the essential constituents of the rock appear; second, the occasional porphyritic character of the hornblende; third, the local abundance of certain accessory constituents, such as titanite; fourth, the deformation of the rock by shearing action, resulting in rude foliation; and fifth, a development of secondary biotite at the expense of hornblende.

Although the granite is abundantly exposed everywhere on the mountain, it is not usually an easy matter to procure fresh material suitable for petrographical studies. The surface is in active process of disintegration, and it is usually only in bottoms of the deep canyons, on the seashore, and on the ridge crests where the products of disintegration are removed as fast as they become loosened, that satisfactory specimens can be obtained. On the higher slopes of the mountain the decay and disintegration of the granite result in a coarse sand of quartz and feldspar.

The prevailing facies of the granite is notably quartzose, and it has plagioclase apparently not less abundantly developed than orthoclase. Hornblende is the chief of the primary ferro-magnesian silicates, for although biotite is commonly present, some of this appears to be of secondary derivation from the hornblende. Titanite and apatite are accessory constituents, and locally, as in the vicinity of Pilarcitos dam, the former mineral is so abundantly developed as to form a notable constituent of the rock. Here titanite crystals are, as usual, sharply idiomorphic, and are of a light cinnamon-brown color. They range in size up to 4 mm. in length. Similar titanites were observed in the granite on Pilarcitos Creek below Locks Creek tunnel. They occur in facies of the granite which are more basic than the average of the mass and in which quartz is poorly represented.

In various parts of Montara Mountain may be observed occasional dark patches consisting of hornblende, or of hornblende and biotite, with feldspar in subordinate proportion, and little or no quartz. They appear to be basic secretions. In the prevalent facies of the granite there are indications of the deformation of the original structure by yielding to shearing stress. These consist of the rudely foliated structure passing locally into a distinctly schistose condition, minute fissures along which dislocation has taken place, and more important shear zones, where the faulting is apparent on a large scale by the displacement of the dikes which traverse the mass. In the more massive portions of the granite the mica is least abundant, and much of it is intimately associated with the hornblende or is inclosed in the latter in such a way as to suggest that it is secondarily derived from it. In the more distinctly foliated varieties the mica is more abundant.

These observations naturally suggest that the mass of the rock in its originally unaltered condition was a hornblende-granite, and that as deformation and shearing progressed mica was developed from the hornblende. The test of this suggestion would be to find the granite in its original undeformed condition. In the basal conglomerate of the Franciscan series, which rests upon the granite, we find bowlders of the latter which have escaped the deformation to which the granite has been subjected since the deposition of the conglomerate. Among the bowlders are some of a perfectly massive undeformed hornblende-granite in which the mica present is clearly epigenetic upon the hornblende. This granite, as represented in the bowlders, has rather a remarkable characteristic in the fact that the hornblende occurs in sharply defined idiomorphic crystals thickly studded in a coarse allotriomorphic granular groundmass of feldspar and quartz. These hornblende prisms have commonly a length of 10 mm. and occasionally measure 15 mm. Their breadth in the direction of the ortho-axis is about 5 mm. The planes which bound these hornblendes are ∞P (110), $\infty P \breve{\infty}$ (010), $\infty P \bar{\infty}$ (100), P (111), OP (001). They thus have the habit of basaltic hornblende. In one specimen of this rock a small scale of molybdenite was observed by Mr. Palache. In such a rock any deformation would be readily apparent in its effect upon the hornblende crystals, but there is no evidence or suggestion of any deformation.

Is this interesting type of rock representative of the original character of the Montara granite? Unfortunately for a very pretty theory this question must be answered in the negative. In the same conglomerate occur other bowlders, which, while also lacking evidences of structural deformation, have the general character of the Montara granite. The handsome rock with idiomorphic hornblendes must therefore be taken to represent a facies of the pre-Franciscan granite terrane which is not now exposed within the limits of the area examined. The original character of the great bulk of the Montara granite is probably not seriously masked by the very moderate amount of deformation to which it has been subjected; and the suggestion which arises upon observing the maximum of mica and the minimum of hornblende associated with the maximum deformation must be entertained cautiously. It seems clear that a portion of the mica is epigenetic; but shearing action is not necessary for the epigenesis, for we have just seen that the secondary mica occurs in the bowlders of hornblende-granite, in which, as is shown by demonstrative evidence, no shearing has occurred. Further, much of the mica in the prevalent facies of the granite can not be definitely ascribed to a secondary origin and is probably an original constituent.

Besides the common variety, there was observed in the walls of some of the canyons near Halfmoon Bay a granite of somewhat different type. The granite here is less coarse and more even in texture than that of the mass of the mountain. Plagioclase is very abundant. The quartz has a yellowish tinge. Biotite is abundant as a primary constituent and hornblende is present in very subordinate proportion, being rarely detected. It is a normal biotite granite, or granitite, and is apparently much more resistant to decay than the hornblendic variety. The relation of the biotite-granite to the main granite mass has not been determined. It is very possibly only a local phase of the same mass. If so, it is a deeper phase. It is, however, quite free from evidences of deformation of structure. Bowlders of this granite occur also in the basal Franciscan conglomerate.

The granitic dikes which intersect the main granite mass of Montara are prominent by reason of their lighter color and the contrast which they thus offer to the rock traversed by them, and also by reason of their greater resistance to decay and disintegration. The dikes occur both in well-defined fissures of small width and no great extension and in irregular masses of greater dimensions. No system could be discovered in the orientation of the dikes. The dike rock presents both the pegmatitic and the aplitic varieties, but the two are not sharply separable, and not uncommonly are found together in the same mass. The aplitic variety is the usual fine-grained granular aggregate of orthoclase and quartz, with a sparse amount of muscovite or in some cases biotite. Small red garnets sometimes appear as a constituent of the aplite. The pegmatite is characteristically composed of large crystals of white orthoclase with broad cleavages, in which are embedded much quartz and occasional sheets of dark-brown mica. Frequently fine-grained aggregates of quartz and feldspar are intimately mixed with these coarse crystals of orthoclase. Red garnets are present here also. They are of small size and are distributed in irregular zones through the pegmatite. Little nests of granular magnetite also occur scattered sparingly through the mass.

GEOLOGICAL RELATIONS.

The geological relations of the Montara granite to the other formations of the peninsula are clear, and afford us a comprehensive view of some of the principal events in the geological history of this portion of the Coast Ranges. The granite is not the oldest formation with which we have to deal. Farther south in the Santa Cruz Range, the same granite is found in irruptive contact with preexisting terranes, among which crystalline limestone or marble is prominent. Of this pregranitic terrane only the merest remnant is preserved within the limits of our field. This consists of the mass of graphite-bearing marble already alluded to, which is embedded in granite on the west side of Pilarcitos Canyon. It is a coarse, white marble, through which are disseminated numerous scales of graphite. This is clearly an inclusion in the granite, or a portion of the crust which immediately overarched it, and indicates that the granite of Montara was originally intrusive into a formation similar to that at the marble quarries of Santa Cruz. From the petrographical character of the granite we may safely assume that it cooled as a plutonic mass (batholite), mantled over by the formations which it invaded from below. All trace of these mantling formations, save this small patch of marble, have vanished under the normal process of denudation, and had vanished prior to the deposition of the earliest of the sedimentary strata which now repose upon the granite. This fact seems to indicate one of two things, either (1) the granite in the region of the San Francisco Peninsula reached a higher zone in the crust which it invaded than it did in the Southern Coast Ranges, or (2), after the consolidation of the granite, it was uplifted higher toward the north, and so became more completely denuded than was the case farther south. However this may be, it is certain that, in time preceding the deposition of the Franciscan series, the stratified rocks over the region of the present Montara Mountain were invaded by a batholitic granite magma, were uplifted far above sea-level, and were thus subject to an erosion so effective as to have almost entirely removed the overlying mantle and to have worn down the granite to a comparatively even surface. Upon this as a basement the Franciscan series accumulated. This heavy sedimentation was followed by a very pronounced uplift, and vigorous denudation was again inaugurated. As a result of this the granite was again laid bare. The land was then depressed, and sandstones, similar petrographically to those of the Tejon, followed by the white shale of the Miocene (Monterey series), were deposited on the reexposed surface of granite. This is clearly seen in the vicinity of the stage road from San Mateo to Halfmoon Bay, which runs east and west just to the south of the field here mapped. These Miocene rocks are shales, which could not have been deposited in very shallow water. It would seem certain that they must have been deposited over the whole of the area of Montara Mountain. The deposition during the Miocene was followed by the uplift necessary for effective denudation, and this uplift was in turn followed by depression, for we find, near Seal Cove, the Pliocene reposing in clearly exposed contact upon a granite surface, no Miocene formations intervening. To this extent are the relations of the granite to the surrounding terranes positively determined

THE FRANCISCAN SERIES.

AREAL DISTRIBUTION.

The formations of the Franciscan series, with their associated intrusive rocks, occupy the greater part of the peninsula. There are two distinct areas of these rocks, one on either side of the Merced Valley, which traverses the peninsula obliquely from northwest to southeast. The southern area is a belt from 4 to 5 miles wide, which flanks Montara Mountain on its northeast side and conforms to its strike. The belt extends from the steeper slopes of the mountain to the edge of the Pliocene terrane (Merced series) which occupies the Merced Valley, and farther south, where this terrane is not now represented, to the shores of the Bay of San Francisco.

The southwestern margin of this belt has already been indicated in tracing the limits of the Montara granite. The northeastern margin may be sketched in a few words. At Mussel Rock the plane of contact of the Merced and Franciscan series intersects the shore-line. From this point southwestward the line of junction of the two series is nearly straight to the upper end of San Andreas Valley. From the north end of San Andreas Lake the line of demarcation between the two series crosses obliquely the flat-topped Buri-buri Ridge, the lower terrane appearing irregularly from beneath the mantle of Pliocene rocks, or from beneath the still younger terrace sands which cover the lower slopes. Occasional outliers of gravel, referable to the latter, are found also upon the surface of the ridge. The details of the distribution are indicated upon the atlas sheets of the peninsula. The edge of the Merced terrane passes beneath the alluvium of the outer slopes of the ridge at a point about 2½ miles west of San Mateo. From this point southeastward the belt of Franciscan rocks occupies the whole of the country between Pilarcitos Creek and the tidal marshes of the Bay of San Francisco, save for some small outlying patches of newer gravels.

The northern area of the series lies in the triangular section of the peninsula which is situated between Merced Valley, the Golden Gate, and the Bay of San Francisco. The formations of the series, with the associated intrusives, cover all of the seemingly irregular cluster of peaks and ridges within the area indicated. Other rocks, however, share with the Franciscan series the occupancy of the area. The Terrace formations and the sand dunes wind in among these hills and ridges and cover their lower flanks.

PETROGRAPHY.

The Franciscan series is a voluminous assemblage of petrographically diverse formations. Much of the geology of the series can be interpreted only by the aid of petrographical studies. None of the formations are interesting by reason of their novelty, for the same rocks occur abundantly elsewhere; but several of them are interesting types, and from their study we arrive at fairly clear conceptions of the conditions which prevailed during the accumulation of the series. Some of these conceptions are, it is true, hypothetical and far from established, such, for instance, as the alternative views which may be entertained relative to the origin of the radiolarian cherts; others are demonstrable truths and may be accepted without question, as in the case of the volcanic origin of several formations of the series. For purposes of discussion the petrographical elements of the series may be broadly and conveniently classified as follows:

(1) A basal formation of conglomerates, coarse grits, sandstones, shaly sandstones, shales, and argillaceous limestones, exposed in the vicinity of San Pedro Point. These rocks require no detailed discussion.

(2) The San Francisco sandstone, the dominant sedimentary formation of the series, consisting of a moderately fine-grained sandstone, fairly uniform in character over large areas, with subordinate beds of shale and conglomerate. The sandstone is uniform, not only in its lateral extension, but vertically for great thicknesses. In the older writings it has commonly been referred to as the San Francisco sandstone, and the term is here adopted from that usage. It is interbedded with the formations 3–5 which are named below.

(3) Foraminiferal limestones.

(4) Radiolarian cherts.

(5) Volcanic rocks, including basaltic lavas, diabases, pyroclastic accumulations, etc. Besides these there are intrusive rocks of a corresponding character, some of which are probably connected with these extravasations, and also intrusive peridotites and pyroxenites, now serpentinized.

In addition, there are certain metamorphic schists, which are the products of the local alteration of the sedimentary or volcanic formations of the series and, according to the writer's interpretation of them, do not constitute a separate formation. There are also a few patches of a peculiar vein-like rock associated with the San Francisco sandstone, but of rather uncertain genetic relations. In his field notes the writer has been in the habit of referring to this as silica-carbonate sinter, and it will be further described under that designation.

The petrographical characters of these different formations will be briefly reviewed in the order named, beginning with the San Francisco sandstone.

THE SAN FRANCISCO SANDSTONE.

Besides the conglomerates, coarse grits, shaly sandstones, and shales which are found in the lower part of the Franciscan series and which are particularly illustrated in the sections on the south side of San Pedro Valley, there is a large body of sandstone in the series, which is without question its most strongly marked characteristic. This sandstone forms the bulk of the sedimentary portion of the series, and, within certain limits, has remarkably constant features, and even more remarkable stratigraphic persistence. The great volume of this and other sandstones of the Coast Range has already been commented on by Becker.[1] It is not proposed to give here an exhaustive description of these sandstones, although the statement of Becker regarding their passage by metamorphism into serpentine and into rocks having the characters of diorites and diabases has excited among petrographers a lively interest in their reexamination. It may be simply stated, by way of anticipation of the conclusions embodied in this paper, that Mr. Becker's views on this point are not confirmed by the writer's studies on the San Francisco Peninsula, where all the rocks concerned are typically displayed.

The prevailing sandstone of the Franciscan series is characterized in the field by a massive aspect due to the thickness of the beds and the obscurity of the bedding planes. Where erosion is not exceptionally active the formation yields a very abundant soil by its secular decay and disintegration. It seems from the writer's experience that the great bulk of the rich sedentary soils of the Coast Ranges are derived from sandstones, and that the soils arising from the sandstones of this series of rocks are perhaps richer and heavier than those from sandstones of later geological age.

Beneath the actual soil the sandstone presents, wherever it may be examined in cliff sections or in cuttings, a more or less shattered appearance, the rock being traversed in all directions by intersecting parting planes. Some few of these are planes of differential movement, along which very moderate shearing action has taken place. The great majority of these intersecting partings show, however, no evidence whatever of movement or of shattering action. They are for the most part ascribable to weathering, and their development seems to form part of the slow process of secular disintegration. The positive evidence in favor of this view is the fact that these partings multiply rapidly toward the surface, and that immediately beneath the soil their intersection has had the effect of chopping the sandstone into small angular pieces, which, by the loosening effect of surface agencies, grade

[1] Monographs U. S. Geol. Survey, Vol. XIII, p. 59.

into the soil itself. Whenever the sandstone is exposed in vertical sections these partings are seen to diminish with depth, and the size of the angular blocks into which they divide the mass becomes larger and larger with increasing distance from the surface, while joints and planes of movement persist. The superficial study of this phenomenon has led to grossly exaggerated views as to the amount of disturbance (shattering) to which the Coast Ranges have been subjected. The sharply marked alternation of wet and dry seasons, combined with the treeless character of many of the ranges, is peculiarly favorable to this disintegration.

Notwithstanding the prevailing massive character of these sandstones, significant glimpses of the stratification are obtained with sufficient frequency to establish their normal bedded character. The bedding is usually in these cases made apparent by the intercalation of beds of shale rather than by any notable differentiation in the character of the sandstone beds themselves. Occasionally, also, thin beds of pebbly conglomerate appear in the formation. Near the surface the sandstone has usually a light yellowish or yellowish-brown color, while the fresh rock is of a greenish or bluish-gray color. The depth to which this surface coloration extends is very variable. In some cases hard knobs of the fresh, unstained rock project through the soil on sharp ridges and steep slopes, but usually the yellowish coloration extends beneath the soil for many feet, possibly 15 feet on an average. The fresh sandstone as found unaffected by weathering is prevailingly a greenish or bluish-gray rock of moderately fine-grained texture, in which the clastic structure is clearly apparent. Flakes of black shale are frequently present and are rather characteristic of the formation. Under the microscope this is found to be composed chiefly of fragments of minerals and rocks, the cross-sections of which exhibit usually angular forms. The chief minerals are, in the estimated order of their abundance, quartz, plagioclase, orthoclase, biotite, hornblende, and zircon. Chert or jasper, andesite or basalt, and schist are fairly abundantly represented among the constituent rock fragments of the sandstone. Black, opaque foliæ appear to represent in thin section the flakes of black shale observed macroscopically. The abundance of the feldspar fragments and the prevailing angular cross-section of the clastic constituents are, perhaps, the most notable features of the slides, of which about forty were cut from representative specimens.

Secondary action, except in some cases requiring special discussion, does not at all mask the clastic structure of the sandstones. Veining is local and exceptional. Occasionally secondary calcite, chlorite, or iron oxide are present. These minerals are, however, minor features of the alteration which has affected the sandstone, and are to be regarded as weathering effects tending to the disintegration of the rock. A more important alteration is the development of the interstitial paste which serves as the cementing and indurating material. This varies in amount.

Sometimes the clastic grains are crowded together and are closely fitted. In other cases they are embedded in the cement so as to be more or less distinctly isolated from one another. This cement appears from a preliminary view of the slides to be composed only to a limited extent of the original finely comminuted clastic material, which may be presumed to have been deposited between the larger fragments of the sandstone.

Recrystallization, together with chemical deposit in the original spaces of the rock, has in many cases developed a secondary aggregate consisting essentially of quartz and feldspar and resembling the groundmass of some quartz-porphyries. The aggregate also frequently contains sericite, and some indeterminate matter. It is exceedingly difficult to discriminate positively between this aggregate and the remains of fine clastic material, or to say how much of it is due to crystallization of the latter and how much to the filling up of original spaces. Another kind of secondary material may sometimes be observed in the same slides with that just mentioned. It is a hazy yellowish or greenish material, which is either pleochroic with the characters of hornblende, or nonpleochroic with the characters of a complex feltwork resembling serpentine.

The elucidation of the cement of these sandstones requires much more detailed study than has yet been given to them, but two facts of general interest appear from the inspection which has been made:

(1) That the chemical activity and recrystallization has in general not affected the larger grains of which the rock is chiefly composed, but has been confined to the portions between them. The only modification which this statement seems to require is that in some few cases the quartz fragments exhibit a granulation suggestive of breaking down as a preliminary or concomitant of recrystallization, and that the feldspars occasionally have a peripheral zone of sericite.

(2) That, in general, the original clastic structure of the rock has suffered no deformation due to pressure or shearing action. Such deformation does occur, but is local, is susceptible of especial explanation, and is not characteristic of the formation within the region examined.

THE FORAMINIFERAL LIMESTONE.

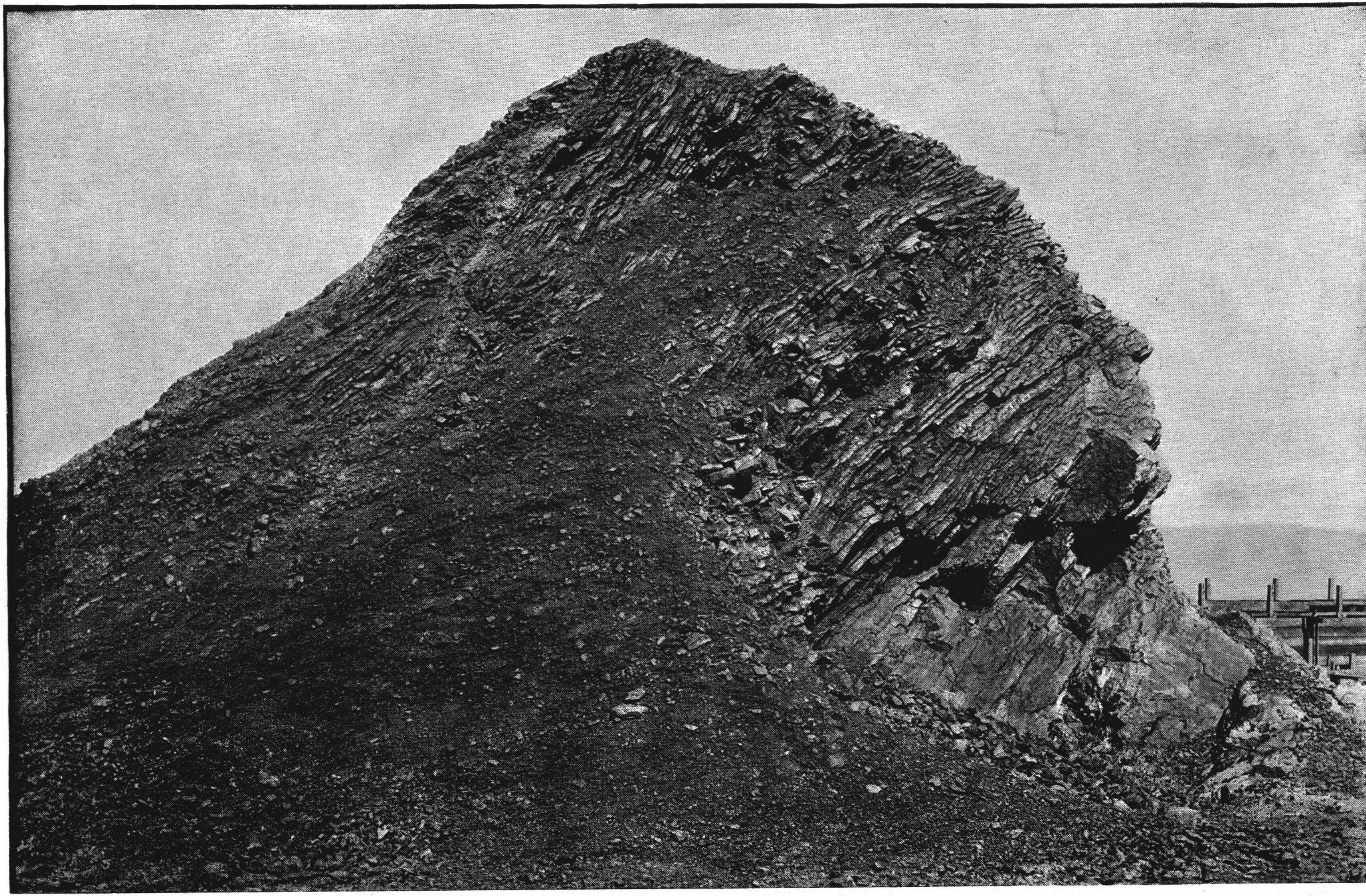
The foraminiferal limestone of the Franciscan series has a fairly constant petrographical character throughout the terrane, although it is found at more than one horizon. It is, in general, a very compact, dense rock, resembling a lithographic limestone. Its color varies from light-drab gray to dark gray, and in either case its weathered surface is usually a very light gray. The rock is generally traversed by veins. These are of two kinds: (1) Minute slender veins of calcite, cutting the rock in all directions, generally without evidence of faulting; (2) larger veins of dark-colored silica, usually an inch or two thick, traversing the rock in parallel attitude, with only an occasional transverse vein of the same kind. These veins have sometimes the nature of lenses. They are traversed by a system of minute veins similar to that affecting the body of the limestone. The larger veins are not so common as the minute veins, and appear to be local developments occurring in a sufficient number of localities to indicate that they are characteristic of the formation. They seem, where best developed, to be parallel to the bedding of the limestone; and it is doubtful whether they are true veins filling fissures, or siliceous deposits contemporaneous with the formation of the limestone. These veins are best displayed in the sea cliff on the north side of the Calera Valley.

When examined closely, the limestone is seen to contain great numbers of clear hyaline spots, of varying size, with sometimes a diameter of nearly half a millimeter. These spots have usually indefinite and blurred outlines, but in favorable cases they may be observed with a lens to have the forms of minute shells. A microscopic study of them shows that they are the remains of Foraminifera. Under the microscope the limestone presents uniformly a dense, structureless aspect, and is composed of a crypto-crystalline aggregate, which, between crossed nicols, appears light whitish-gray, by reason of compensatory polarization. The individuals of the aggregate are so small that they can not be discriminated one from another. The sections afford no suggestion of deformation. The shapes of the Foraminifera are not deformed. The character of the limestone and its relation to the included Foraminifera clearly indicate, not that the rock was formed by an accumulation of the débris of the shells, but that it is essentially a chemical precipitate in which the Foraminifera were more or less sporadically entombed.

There are one or two local variations from this general character which deserve a passing mention. Occasionally, the color of the limestone is almost black, as in portions of the beds exposed 2½ miles due east of San Pedro Point. At other times it is reddish, but this character is very local. Portions of the beds on the crest of Fifield Ridge are rather dark, and have a peculiar concretionary, pisolitic structure. The concretionary pellets show concentric structure on the weathered surface. The pellets are darker than the interstitial limestone, and seem to owe their character to the presence of an admixture of clay or silt, since a considerable amount of the latter is left as a residue on dissolving a fragment of the rock in acid. Chemically, the foraminiferal limestone is a pure carbonate of lime, with no magnesia.

THE RADIOLARIAN CHERTS.

Of the formations which constitute the Franciscan series the most salient and remarkable are the radiolarian cherts. Quantitatively these rocks are not so important as the San Francisco sandstone. They are neither so thick nor so persistent as the latter. Their excessive hardness, however, and their resistance to weathering and decay,



RADIOLARIAN CHERT, HUNTERS POINT.

make them the best exposed formation in the series; and the most rugged topographic features of the terrane are due to their presence. The interest which is thus excited in these rocks by their bold outcrops is intensified by the most cursory inspection of their structural and petrographic features. They are prevailingly of a dull brownish-red color, particularly in the thicker and more evenly bedded portions of the formations. Yellow and green colors are, however, fairly abundant. White, colorless, blue, purplish, gray, brown, and black cherts are also seen, but the coloring is usually local and is not characteristic of extensive masses of the rock. Where the cherts have been subjected to heat, as at the contact with eruptive rocks, they are of a brilliant vermilion-red color.

The bedding of these cherts is one of their most remarkable features. The sections exhibiting the bedding are numerous and excellent. Not only is it well displayed in the natural outcrops of the formation, but it is seen to even greater advantage in the many rock cuttings which have been made in the hills of San Francisco, in the work of extending and grading streets, and for the purpose of procuring road metal. All of these exposures and cuttings show a striking constancy in character of bedding. The essential feature of the latter is the alternation of thin sheets of chert with partings of shale. The shale and chert are usually of approximately the same color. In the most representative sections the sheets of chert range, generally, from about 1 to 3 or 4 inches in thickness, with an average of perhaps 2 or 3 inches. Occasionally there are much thicker beds of chert, but their presence scarcely detracts from the general thinly and evenly bedded aspect of the sections. The shaly partings between these sheets of chert range usually from about one-eighth to one-half an inch in thickness, but they are frequently also mere films. As the formation is frequently exposed in sections many hundred feet in thickness, we have the remarkable phenomenon of an alternation of thousands of these sheets of chert with the corresponding layers of shale. In the common red phase of the formation, which is by far the most abundant, the regularity of these thinly sheeted stratifications is amazing. In other portions of the formation, where red iron oxide is less abundant, both in the chert and in the shaly partings, the regularity is much less marked, and the sheets of chert assume lenticular forms. In these less ferruginous varieties the chert beds have their maximum thickness, and the shaly partings their minimum, and the formation also here frequently presents sections to which the description above given for the most representative sections would not apply. The parting planes have little or no shale, and the beds or lenses of chert exhibit a thickness ranging from several inches to several feet. In these places the formation is very massive in aspect, having little structural resemblance to the thinly bedded greater portion. There are all possible gradations, from the massive to the thinly bedded variety.

Petrographically the radiolarian cherts are not uniform. In many cases they are true jaspers, and they have been so designated in some of the earlier descriptions of them. In other cases the silica of which they are composed is chiefly amorphous, and the rocks are of a flinty or hornstone character. In still other cases the proportion of iron oxide and other pigment present is so large that the cherty character disappears, and the beds locally become so soft as to be easily scratched with a knife. In a few cases, notably in those phases devoid of coloring matter, they have been observed to pass into a quartz rock, in which the flinty or jaspery character is absent and the mass does not differ essentially from vein quartz. This quartz-like condition is, however, exceptional, and is probably due to special local causes.

In view of this variation in petrographical character, it has been deemed best to refer to these rocks by the old and familiar name of "chert," as the only petrographical term sufficiently comprehensive to include all of their common forms. It is clear from the usage in recent literature that this term is being adopted for a large body of siliceous rocks characterized the world over by the presence of radiolarian remains. The term "phthanite" has been applied by Becker to these rocks, but the writer is loath to follow him in this usage. As Becker states, the term was intended by Haüy for certain siliceous rocks occurring with limestones. Such phthanites, in the original sense of Haüy, occur in this same field, and if the term is to be used at all it should be applied to them. In almost any specimen of these cherts that may be examined critically with a lens, minute, round or oval, dark hyaline or whitish dots may be observed scattered throughout the base of the rock. These are the residual casts of Radiolaria, the characteristic fossils of the formation.

When a suitable series of these cherts is viewed in thin section under the microscope a gradation may be observed from those which are composed almost wholly of amorphous or isotropic silica to those which are a holocrystalline aggregate of quartz granules. In the most isotropic sections there are, however, numerous minute scattered points in the field, which polarize light. These can not be separated in any sharp way by the highest powers from the isotropic base. They are not inclusions, but centers of incipient crystallization in the amorphous rock. They correspond to the products of devitrification in glass. In other slides these centers of crystallization are much more thickly crowded, and definite areas composed of interlocking granules of quartz appear, interlocking, also, with the isotropic base. The actual boundaries of these areas can be made out only with difficulty and uncertainty, owing to the fact that the quartz granules are characterized by a molecular tension, which results in an undulatory extinction as the stage is revolved between crossed nicols. In still other slides these areas coalesce and the proportion of amorphous base to the whole rock becomes very small. Finally, there are slides which show a holocrystalline aggregate of interlocking quartz grains. In most cases the grains are characterized by a more or less pronounced molecular tension, as is evidenced by undulatory extinction, which causes them to somewhat resemble chalcedony. The discrimination between the amorphous and the crystalline silica is easy in those varieties poor in iron ore pigment; it is difficult in proportion to the abundance of the obscuring pigment. The gradation thus observed in a series of slides from specimens taken at random seems clearly to be a gradation in time, and not merely a gradation in space. It indicates the different stages of a process of crystallization in a solid amorphous mass. If this be granted, there seems to be no good ground for doubting that in general the holocrystalline cherts, or jaspers, were originally amorphous silica, and that they owe their present character to a process of crystallization quite analogous to that of devitrification in the volcanic rocks.

The question now arises, What is the mineralogical character of the amorphous silica? It is clearly not any one of the numerous cryptocrystalline varieties of silica. It is perfectly isotropic. If we refer to the books we find that opal is the only variety of silica which is strictly amorphous. But this differs from opal. A fragment of chert that showed a large proportion of isotropic base was found to scratch quartz distinctly with comparative ease. It has a specific gravity of 2.628, and although it yielded a little water in the closed tube, the amount of water was notably less than that derived from a corresponding quantity of common opal. We thus seem to have a condition of slightly hydrous amorphous silica much harder and much heavier than opal.

Scattered through the slides of these cherts, whether they be amorphous, semicrystalline, or holocrystalline, there may usually be observed, in ordinary light, circular or oval clear spaces or clear rings free from pigment. Between crossed nicols these clear spaces are seen to be occupied by chalcedony. They are the casts of Radiolaria, and occasionally remnants of the spines and latticework may be detected. These areas and rings are usually more sharply defined in the amorphous cherts, and are somewhat indefinite in outline, yet distinct as areas, in the holocrystalline varieties. In thin section they are most readily observed in the red cherts, by reason of the contrast which they make with the pigmented matrix.

In addition to these general petrographical characteristics, there are a few of subordinate or local interest to be mentioned. There seems to be a law of paragenesis connecting the oxide of manganese with the radiolarian cherts. Usually this oxide is not found in masses, but only as films and stains in the crevices of the chert and in the bedding planes. In some cases this staining is so abundant that the body of the chert is locally blackened. In the same formation at Red Rock, in the Bay of San Francisco, there is a thick deposit of oxide in the form of psilomelane lying in the bedding planes of the chert, which are here nearly vertical. Other similar deposits are known in the Coast Ranges in these same cherts. So far as the writer is aware the manganese ore is confined to these cherts. A second interesting feature of the cherts is their passage locally into an iron ore. A feature of the cherts which is generally characteristic, but which varies in the degree to which it is developed, is the system of minute fissures which traverse the hard beds transverse to the bedding planes. These fissures are frequently fault planes along which have taken place tiny dislocations that are apparent in the steps which then mark the otherwise even surfaces that constitute the upper and lower limits of the chert beds. Frequently these fissures are lines of very evident veining, and doubtless all of them would prove to be veins if examined in thin section. The vein matter is quartz, which is usually white or hayline, while the chert is colored. None of these fissures, faults, or veins pass through the shaly partings. The plasticity of the latter has prevented their development, and each thin sheet of chert has its own system of fissures.

The origin of the radiolarian cherts is a problem full of the deepest interest to geology. Are they deep-sea deposits? Is the silica of which they are composed wholly of organic origin? What mysterious alternation of conditions can be imagined to account for their remarkable bedding? What was the rate of their accumulation? These and many other questions naturally arise in the mind as soon as the remarkable character of the formation is appreciated. The suggestion that they are deep-sea deposits seems to be irreconcilable with their intimate association and interbedding with sandstone. It seems clear from the character of the cherts that they must have been deposited in water sufficiently deep or sufficiently far from shore to be beyond the range of ordinary littoral sediments. Even the shale which forms the parting between the chert beds is not an ordinary clay shale.

A specimen of the shale was digested by hydrochloric acid, and it assumed a deep chrome-green color after the red iron oxide had been dissolved out. This green material was analyzed qualitatively by Mr. Ransome at the writer's request, and was found by him to be composed essentially of silica and iron, with considerable magnesia and a small amount of alumina.

In thin sections of the shale the highest powers of the microscope fail to reveal any clastic material or clastic structure. Only a homogeneous isotropic base is observable, in which are scattered a few centers that polarize light feebly and appear to be due to incipient crystallization in place. These are far from the characters of a common clastic shale. In so far, therefore, as the petrography of the rocks is concerned, they might be deep-sea deposits, and it is their interbedding with common sandstone which checks this supposition. As regards the organic origin of the silica of which the chert is composed, it seems to the writer that there are features both in the slides and in the field occurrence of the formation which do not harmonize with this supposition. In the slides having the radiolarian remains, the latter generally occur as casts of forms embedded in a matrix of silica which shows no evidence whatever of organic origin. The cavities of the Radiolaria have been filled with chalcedonic silica, and are in definite contrast with the nonchalcedonic matrix. The discrete character of the fossils is significant of their mode of accumulation. The silica seems to have been an amorphous chemical precipitate, forming in the bottom of the ocean in which the Radiolaria thrived. The dead Radiolaria dropped into this precipitate, became embedded in it, and were so preserved. The state of preservation is variable, but this is ascribable to the molecular changes that have been in progress in the rock since its solidification, or to the solvent action of the same agencies which held in solution and precipitated the silica.

It thus seems to the writer that the bulk of the silica can not be proved to be the extremely altered débris of Radiolaria. The direct petrographical suggestion is that they are chemical precipitates. If now we accept this hypothesis, it becomes apparent that there are three possible sources for the silica so precipitated, viz (1) siliceous springs in the bottom of the ocean, similar to those well known in volcanic regions; (2) radiolarian and other siliceous remains, which may have become entirely dissolved in sea water; and (3) volcanic ejectamenta, which may have become similarly dissolved. The last is the least probable, because we are not actually familiar with such a reaction as the solution of volcanic glass by sea water. Our ignorance is, however, no proof that such solution may not take place under special conditions. Setting this third possibility aside, let us consider to which of the other two the field evidence points.

If the silica were derived from the solution of organic remains by sea water, or, indeed, directly from organic débris, we should expect to find the cherts having a vast extent of fairly uniform thickness. On the other hand, if the silica were derived from siliceous springs we might have the formation developed in lens-like masses of varying thickness at different centers. The field evidence agrees in an unmistakable way with the second of our supposed conditions. The radiolarian cherts occur throughout the field, and, indeed, throughout the Coast Ranges, in a sporadic way. Although some of the occurrences are many hundred feet thick, they appear to thin out rapidly and do not form sheets comparable in extent to the San Francisco sandstone. Most of the individual occurrences, moreover, are of very limited extent, occupying only a few acres, or only a fraction of an acre, and it seems impossible to conceive that they had any other than a very local origin. Great numbers of these small patches of chert occur in the sandstone, which are so small that they can not be represented in the mapping without gross exaggeration. The hypothesis of the derivation of the silica from siliceous springs and its precipitation in the bed of the ocean in local accumulations, in which radiolarian remains became embedded as they dropped to the bottom, seems, therefore, the most adequate to explain the facts, and there is nothing adverse to it so far as the writer is aware. The abundance of the Radiolaria may be due to the favorable conditions involved in the excessive amount of silica locally present in the sea, or simply to the favorable conditions for preservation afforded by this kind of rock. If the springs were strong, the currents engendered might in some places have been sufficient to deflect sediment-laden countercurrents, and this may serve to explain the general absence of clastic material in the chert.[1]

It is entirely probable that radiolarian remains will be found in rocks which represent sediments deposited in the same sea as that in which the cherts were locally developed.

The alternation of beds of chert with partings of shale may perhaps be ascribable to a rhythmical or intermittent action of the springs. But in any theoretical consideration of the cherts the stratification is their most obscure feature. The comparative rate of accumulation of these rocks can scarcely be guessed at.

VOLCANIC ROCKS — ERUPTIVE AND INTRUSIVE.

There is abundant evidence of contemporaneous volcanic activity during the deposition of the sedimentary rocks of the Franciscan series. Sheets of amygdaloidal lava and of volcanic tuff interstratified with the sandstones and limestones are a salient characteristic of the series. The volcanic activity was evidently intermittent, for we have great thicknesses of sandstone, with shales and limestone, quite free from any volcanic admixtures, separating volcanic accumulations. This fact carries with it the suggestion that, before the entire series had accumulated, the lower portion, which had already been deposited, must have been to some extent invaded by the volcanic material in its passage to the surface vents, where it was extravasated in the form of lavas or tuffs, to be buried by later sediments. This inference is borne out by field observations. Although the greater portion of the volcanic material is interstratified, yet it is evident in some cases, and probable in others, that the igneous rocks are intrusive in the sedimentary strata. There seems to be no good ground for sharply separating such intrusive masses from those which have been extravasated as flows. The rocks are petrographically similar, and it seems reasonable to regard both the extrusive and the intrusive occurrences as not radically different manifestations of the same volcanic activity. Both may be properly said to be contemporaneous with the sedimentary rocks in the sense that the activity which produced them began and ceased within the time occupied in the accumulation of the series.

[1] The writer is informed by Mr. W. D. Johnson that the springs of Mono Lake issue with such force that they create a slight convexity on the surface of the lake, over which it is difficult to propel a small boat toward the center, so strong is the radial current.

The rocks thus classed together as contemporaneous volcanics have not yet been exhaustively studied. They seem to present few petrographical problems calling for especial investigation, and they have been subjected only to such an examination as would serve for their identification. For this purpose about seventy-five thin sections have been examined. This examination shows that these rocks fall into at least four general classes, which, although petrographically distinct, are probably genetically allied, viz, olivine diabase, diabase, olivine-free basalt (with perhaps augite-andesite), and volcanic tuffs. Brief descriptive notes of these four general classes are given below. In the geological mapping of this region it is impossible to indicate the relative distribution of the different rocks, and they are classed together as volcanic.

Olivine diabase.—Olivine diabase has been found in association with the Franciscan series at only three localities, and in each case under analogous and peculiar circumstances. The localities are (1) the west side of Belmont Hill, at an altitude of about 425 feet; (2) the southwest side of Buri-buri Ridge, near the north end of Crystal Springs Lake; and (3) a hillside about 1⅝ miles south-southeast of Mussel Rock. The peculiarity of the occurrence in each case is that the rock is found in the form of a group of bowlders of disintegration, lying loose in the soil and weathered on all sides. In no case could the rock be found in situ. It seems probable in each case that the bowlders found are residual masses resulting from the disintegration of small dikes, the general outcrop of which has been lowered beneath the soil by weathering.

In the Belmont Hill occurrence the olivine is abundant and mostly fresh. It has the usual reticulated veins of incipient decomposition, and along these veins, and on the periphery of the crystals the mineral is altered to serpentine. The augite is of a brownish-violet color and is pleochroic. It is quite fresh and shows no decomposition, even of an incipient character. The plagioclase is in the usual lath shaped forms and is more or less cloudy. There are present, also, titanic iron in scattered grains, secondary magnetite in the veinings of the olivine, and nests of chlorite. The structure of the rock is ophitic. The rock from near the north end of Crystal Springs Lake is composed essentially of abundant olivine, nearly colorless augite and lath-shaped plagioclase. The ophitic structure is very sharply pronounced. The rock at its third place of occurrence, on the ridge southeast of Mussel Rock, is more basaltic in its character than in either of the two other localities. It consists essentially of a groundmass of plagioclase, augite, iron ore, and probably glass, in which are embedded many phenocrysts of olivine. In the groundmass the plagioclase has the usual lath-shaped forms and the augite and iron ore occur in irregular granules. The phenocrysts are often sharply idiomorphic, but are probably about half changed to serpentine. The rock is perhaps better designated a basalt than a diabase, but it is in general analogous to the two diabases with which it is here considered.

Diabases.—The diabases found with the beds of the Franciscan series are separable into two varieties. The less common variety is not so fine grained as the other and is characterized especially by its deeply colored and strongly pleochroic constituent augite. The pleochroism and absorption phenomena are those of augite containing titanium. This augite is in the usual ophitic relation to the lath-shaped plagioclase, which is often in part cloudy. Titanic iron with leucoxene is a rather persistent constituent. No olivine has been detected in these rocks, but rather large areas composed usually of aggregates of spherulitic chlorite, and also less frequently of serpentine, may represent what were once olivine crystals. These areas of chlorite and serpentine are not infrequently accompanied by calcite. These rocks are not improbably geneticallyallied to the olivine diabases mentioned above. They are very similar in macroscopic appearance, and in some of their microscopic aspects, to the diabase from Point Bonita,[1] described by Mr. F. L. Ransome. The augites particularly seem to be the same.

The localities at which this variety of diabase has been found are so few that they may be especially noted. The most important locality, by reason of the excellence of the exposure, is on the north side of Belmont Creek Canyon, on the wagon road, near the reservoir, 2 miles west of Belmont Station. Here, in vertical cuttings, the diabase is exposed in approximately flat-lying sheets, associated with thin partings of fragmental material and amygdaloidal basalt. It is overlain by radiolarian cherts. The field evidence indicates that it is a surface flow, but is not conclusive. The second locality is on a hillside about 1¾ miles east of San Mateo dam. It is overlain by radiolarian cherts, as in the Belmont Creek section, and may represent the same stratigraphic horizon. The only other locality for the rock which is at present known is in the canyon on the east side of Las Pulgas Ridge, at a point about 1 mile north of the almshouse. The relation of the rock to the sandstone is not clear.

The second and by far the more common variety of diabase is much finer grained and can usually be discriminated from the dense non-amygdaloidal basalts only by microscopic examination. It is very probably only a form of the latter, which are abundantly represented in the series. The diabase is usually composed of an ophitic aggregate of cloudy plagioclase and nearly colorless augite, the latter being very commonly uralitized and less commonly chloritized. Titanic iron is a common accessory, usually associated with leucoxene. Chlorite is a common secondary mineral. In the prevailing forms there are no evidences of deformation of the rock structures.

An exceptional variety of rock occurs a mile north-northeast of San Mateo dam, on the eastern slope of Buri-buri Ridge. It is a light-gray

[1] Bull. Dept. Geol. Univ. Cal., vol. 1, No. 3, p. 88.

rock, having the aspect of an andesite. In thin section it is seen to be composed essentially of a compact feltwork of lath-shaped feldspars, with perhaps a very small proportion of glass. There are minute grains of what may be a colorless pyroxene, and numerous shred-like areas of iron oxides and chlorite. In this as a groundmass may be detected an occasional phenocryst of feldspar. The rock recalls the descriptions given of the bostonites; but further investigation is necessary before it can be finally classed. In the field it occupies the summit of a shoulder of Buri-buri Ridge, resting on sandstone, and may possibly be the remnant of an intrusive sheet.

Basalts.—The rocks here classed generally as basalts may usually be discriminated from the fine-grained diabases by their more or less prevalent amygdaloidal structure, or by their occasional porphyritic character. Both of these features are, however, frequently lacking, and the dense greenish-gray rock presents no characters which seem to distinguish it from the diabase. It is only when a considerable number of hand specimens have been collected and thin sections of them examined that the sharp separation of these volcanic rocks into diabases and basalts can be made; and then it is sometimes found that two specimens, one a diabase and the other a basalt, have been taken from what in the field was regarded as a single formation. The decayed condition of the surface portions of these rocks of course renders the discrimination of a volcanic mass into its constituent formations extremely difficult; but notwithstanding this fact it is the opinion of the writer that the fine-grained diabases and the basalts are usually not essentially different formations. Some of these basalts are quite similar to those of Point Bonita, described by Mr. Ransome,[1] being spheroidal and variolitic. These are usually clearly intrusive.

The basalts vary greatly in minor features, and it is not improbable that a portion of them will be found on more critical study to belong with the augite andesites, while others have the characters of augite porphyrites. In general they are hypocrystalline rocks, in which the proportion of glass varies greatly. Plagioclase is the dominant, and in some cases the only, crystalline constituent. It occurs in the usual feltwork of lath-shaped crystals. With the plagioclase there is usually augite in small granules, although in some cases the rock seems to have solidified as a glass, embedding the plagioclase before the separation of the augite. No olivine has been detected. Magnetite is in some cases abundant, and in others only sparingly present. Occasionally the rock is reddish and the slides of it murky from the presence of iron oxide. Cloudy areas of chloritic material characterize nearly all the slides. In some cases there are large phenocrysts of augite and plagioclase, and the rock then presents the character of an augite porphyrite. A pronounced parallelism in the

---

[1] Loc. cit.

disposition of the plagioclases is sometimes apparent, indicative of flow in the solidifying magma. An amygdaloidal structure is fairly common, though variable in character. In some cases the amygdules are few and widely scattered, in others they are closely crowded together. The amygdules are perfectly spherical, or oval, or somewhat irregular in their boundaries. The chief secondary minerals filling the vesicles are quartz, chalcedony, chlorite, and calcite, the last two being the most abundant. Any or all of these minerals may be found in the same amygdule. The lath-shaped feldspars frequently exhibit a tangential disposition with reference to the amygdules.

Volcanic tuffs and breccias.—Tuffs and glass breccias form an important element in the volcanic portion of the Franciscan series. The tuffs may frequently be recognized in the field by reason of their coarsely clastic character and their disposition in beds stratified with amygdaloidal lavas, the angular fragments composing the beds being, where recognizable, pieces of basalt. In many cases, however, they are finegrained and present a compact, homogeneous appearance, so that their true character is revealed only by microscopic study. When examined under the microscope these tuffs are usually found to be composed of fragments of basalt scattered through a finer matrix, in which there has been considerable secondary action, giving rise to silica in the form of chalcedony. Sometimes there are fragments of glass free from embedded crystals. In some cases fragments of crystals of augite and feldspar are freely mingled with the fragments of basalt. In certain beds the matrix in which the volcanic fragments are embedded is a limestone, and points to accumulation of the volcanic material on a sea bottom where a limestone was in process of deposition. In other cases the volcanic material is freely mixed with the detritus of which the sandstones are formed. In still other cases, the tuff consists of a fine ash, in which are embedded fragments of crystalline schists, together with fragments of augite and feldspar.

The glass breccias were not recognized as such in the field, but were discovered in thin sections. Their character is obscured in the hand specimens by the thorough silicification to which they have been subjected. The silica assumes the conditions of opal and chalcedony, and has completely filled all the interstitial spaces, so that the rock presents a compact, though somewhat mottled, aspect. The usual structure of such breccias, due to viscous flow and fracture, together with the development of vesicles, is perfectly preserved, notwithstanding the silicification. Lath-shaped crystals of plagioclase may in some cases be observed embedded in the glass. In the irregular spaces occupied by the silica the secondary hornblende has in some cases been developed in the form of slender, green, pleochroic needles radiating from the walls of the silica-filled cavity toward its central part. All of these glass breccias have a greenish color and are not to any notable extent stained by iron oxide, although the latter occurs locally.

In addition to the igneous rocks above described, which are regarded as various manifestations of volcanic activity contemporaneous with the deposition of the Franciscan series as a whole, there are certain other intrusive rocks of limited extent which can not, either on petrographical grounds or by reason of their field relations, be connected with the volcanic extravasations. They may, possibly, represent residual plugs in the vents from which the volcanic material emanated, but it is also possible that they may be much later, and be associated with the intrusive rocks found with the serpentine of the Potrero and Hunters Point, to be described farther on. These rocks are not found usually in extensive masses, and occur at only a few localities. They have usually the characters of uralitic gabbros, in which the proportion of feldspar varies considerably. Occasionally quartz is present; and in some cases they seem to have absorbed portions of the sandstone into which they are intrusive, and the resultant mixture has solidified as a rather acid granophyric rock.[1] These rocks require a more thorough petrographical study than has yet been given to them, and their discussion is therefore reserved to a future occasion.

METAMORPHIC SCHISTS.

The petrology of the metamorphic schists of the Coast Ranges is full of large and intricate problems. The rocks are represented on the Peninsula of San Francisco but poorly, and the field is not favorable for their study. Their investigation can be effectively undertaken only in the light of results yet to be obtained from occurrences more favorably revealing the space relations of the rock masses; and it is only by analogy with a general condition, which is prevalent in the Coast Ranges, that the hypothesis here entertained respecting their origin will be fully justified. The areas occupied by these schists are so small and so sporadic that they can not be adequately represented in the geological mapping of the peninsula. They occur in small patches, usually not more than a few hundred feet in extent, and their relations to the surrounding rocks are in most cases perplexingly indefinite, owing to the concealment of the contact by soil.

In view of these unfavorable conditions no attempt has been made to subject the metamorphic schists to exhaustive examination. The time and energy necessary for such investigation can be more profitably applied to the same problem in other parts of the Coast Ranges. A few observations are, however, offered as a contribution to the subject; and a hypothesis, which has a wider basis than the observations made in this particular field, is suggested for the origin of the greater part of the common metamorphic schists of the Coast Ranges.

The schists have a very wide range of petrographic character and appear to represent various stages of the alteration of rocks originally

[1] Since this was written Bayley's paper on the contact phenomena of Pigeon Point has appeared (Bull. U. S. G. S. No. 109), which may be profitably consulted for instances of such interfusion on a large scale.

very diverse. Among the least-altered forms may be recognized: (1) Rocks not essentially different from the San Francisco sandstone, save for a rudely schistose structure with the appearance of having been sheared; these grade, often in the same mass, into micaceous schists with glossy sheen surfaces and less commonly into bluish schists whose color is due to the presence of needles of blue amphibole. (2) Bluish shales, being apparently the common shale occurring as subordinate beds in the San Francisco sandstone, in which needles of bluish amphibole have been developed. (3) Volcanic tuff, such as is common in the Franciscan series, save that it has acquired a bluish appearance, due to the development of blue amphibole needles, and has assumed a rude and irregular, often scarcely perceptible, schistosity. (4) Massive basic rocks, probably referable to the basalts and diabases of the Franciscan series, but with a rather abundant development of blue amphibole. The schistosity in these is often very feebly developed.

From these less-altered forms of the common rocks of the Franciscan series, gradations may be traced into schists in which all trace of the original rock is lost. These highly altered forms are of two general classes: (1) The light-blue, fissile schist which is commonly called "glaucophane schist," although it is doubtful whether all the blue amphibole is really glaucophane.[1] (2) Various micaceous, hornblendic, and chloritic schists with or without a subordinate proportion of blue amphibole. It is not yet known to what extent the sedimentary rocks, such as sandstone and shale, give rise to the more pronounced varieties of the blue amphibole schist. In many the blue amphibole is certainly a product of the metamorphism of such rocks, but it can not yet be asserted that it is developed to the exclusion of the micas, green hornblende, chlorite, etc.; and it seems probable from the observation of the writer, that those schists with micaceous sheen surfaces and with little or no blue amphibole are, as a rule, the result of the metamorphism of sedimentary strata; while the blue amphibole schists may arise from the metamorphism of the volcanic tuffs, the massive volcanic rocks, or the sedimentary strata.

From the sporadic and limited occurrence of these schists it is apparent that we are not dealing with a case of regional metamorphism. The very evident derivation of the schists from the normal volcanic and sedimentary formations of the Franciscan series points directly to contact metamorphism. This suggestion necessitates for its verification the identification of the schists as portions of the contact zones of intrusive masses. This identification is in many cases extremely difficult by reason of the absence of an intrusive rock in the *immediate* vicinity of the area of the schist. In some few cases the schist areas have a very definite relation to dikes and laccolitic lenses of serpentine, and some of the most highly altered phases of schist that have been found, both of the

[1]Cf. Bull. Dept. Geol. Univ. Cal., vol. 1, No. 6. On a rock from the vicinity of Berkeley containing a new soda amphibole, by Charles Palache.

micaceous and the blue amphibole varieties, have been taken from the immediate contact with the serpentine. In these cases there seems to be little doubt that we are dealing with a contact zone. In other cases, however, we have the immediate contact of serpentine and sandstone well exposed with no perceptible development of schist at the contact and little alteration of any kind appreciable to the unaided eye beyond a narrow zone of hornfels. It seems clear, therefore, that the metamorphic action of intrusive peridotite upon the rocks which it invades is not uniform, and the conditions which determine in some cases a maximum and in some cases a minimum of metamorphism are not yet known. This metamorphic action of intruded serpentine with its variable intensity is beautifully established by the investigations of Mr. F. Leslie Ransome, conducted in the laboratory of the University of California, on the geology of Angel Island, Bay of San Francisco. This study was undertaken by Mr. Ransome, at the writer's suggestion, as that of a field which promised particularly definite and satisfactory results. The investigation, the results of which are published elsewhere,[1] shows unequivocally the presence of a contact zone on the margins of a dike of serpentine which traverses the island. It also shows that both the breadth of the contact zone and the intensity of the action at different parts of its course are very variable.

If, now, we recognize that an intrusive peridotite under certain favorable conditions may affect a profound local alteration in the inclosing rocks, certain considerations may be presented which favor the supposition that most of the occurrences of metamorphic schists which are known in our field, even where they are not now in observable juxtaposition with any intrusive mass, are portions of the contact zones of peridotite invasions. The most significant fact bearing on this hypothesis is the distribution of the schist. All of the patches of schist which have been observed lie along a belt of country which is characterized by a great abundance of serpentine in the form of dikes and laccolitic lenses, viz, Buri-buri Ridge and its extension southeastward across San Mateo Canyon. The occurrence of patches of schist in this belt, and their absence in other portions of the field where no serpentine occurs suggests the dependence of the metamorphic rock upon the serpentine. When with this hypothetical dependence there is coupled the fact that some of the most highly altered schists are known to occur at the actual contact with serpentine, the hypothesis becomes a strong one. How, then, can we harmonize the occurrence of discrete patches of schist, apart from any known mass of serpentine, with the general hypothesis that they represent contact zones? There are two possible and satisfactory explanations. The first of these is that the intrusive peridotite, from which serpentine is derived, commonly assumed the forms of approximately horizontal lenses or sheets, and

[1]Bull. Dept. Geol. Univ. Cal., vol. 1, No. 7.

these sheets have been in some cases entirely removed down to the floor upon which they rested. This floor was probably variably affected by the metamorphic action of the peridotite, and since the removal of the serpentine has been variably sculptured by the forces of erosion. Thus we might get patches of schist which, though now entirely discrete, were originally portions of a contact zone somewhat unevenly distributed in a roughly horizontal attitude. The second possible and entirely satisfactory explanation is, that very probably there are throughout this tract of country many dikes and other intrusive masses of peridotite, which did not penetrate upward as far as the level represented by the present surface of the land. Some of these may be but a short distance beneath the surface, and be manifest only by their overlying contact zone of metamorphic rocks.

Another important consideration which must be borne in mind in attempting to account for difficult cases is that the intrusive serpentine may not be responsible for all of the metamorphism. The period of accumulation of the strata of the Franciscan series was in general a period of volcanic activity. It is entirely probable that the lower portions of the series were traversed by igneous rocks which were eventually extravasated as constitutents of the upper portion of the series. In the case of Angel Island, Mr. Ransome has clearly shown that intrusive rocks other than serpentine may develop a metamorphic contact zone in the San Francisco sandstone. The general fact, however, of the distribution of the schist patches on the San Francisco Peninsula along the serpentine belt of Buri-buri Ridge, and their absence in other portions of the field where there is no serpentine, seems to the writer to indicate that, although there may be special cases when intrusive rocks other than serpentine have affected local metamorphism, yet, in this particular field the peridotite intrusions have probably produced by far the greater part of it.

The considerations which have led to this conclusion have an application far beyond the field under immediate discussion. Believing that the geological conditions which obtain in the vicinity of the Bay of San Francisco are representative of the Coast Ranges generally, the writer feels warranted in formulating an hypothesis as a guide for future work in a very important line of investigation in Coast Range geology. There are two general groups of metamorphic rocks in the Coast Ranges, and neither of these can be properly classed as the products of regional metamorphism. The older metamorphics are pre-Franciscan, and they form the broad contact zones of irruptive granites, such as those of the Santa Lucia and Santa Cruz mountains. These rocks form the eroded and truncated basement upon which the Franciscan series rests. The second group of metamorphics belongs to the Franciscan, and possibly also to later series of rocks, and are chiefly the contact zones of irruptive peridotites and of basic intrusives other than peridotites.

In this hypothesis the characteristic radiolarian cherts are not classed as metamorphic, for although chemical and physical changes have gone on in the silica of which they are composed, these changes are of a totally different order, and are due to causes different from those operating to effect the metamorphism of the schists. Neither are the rocks which Becker classed as metamorphic under the terms pseudo-diabase and pseudo-diorite here recognized as metamorphic, but as true igneous rocks.

SILICA-CARBONATE SINTER.

The formation to which this name is tentatively applied is not abundantly represented on the San Francisco Peninsula, nor is its origin clearly understood. In other parts of the Coast Ranges, however, it is a more extensive formation, and from its occurrence in irregularly bedded sheets or lenses in the sandstone and its petrographical character the hypothesis is at present entertained that it is a chemical deposit from waters holding both silica and carbonates in solution. Should this hypothesis eventually prove acceptable, the term applied to the rock will be justified. The most doubtful question concerning the formation, however, is whether it is contemporaneous with the sedimentary strata, with which it is usually found bedded, or is a secondary or vein formation along the bedding planes.

Petrographically the rock is an exceedingly irregular and intricate mixture of silica in the form of opal and chalcedony and carbonates of lime, magnesia, and iron. The silica is present usually in the form of a meshwork of veinules which, however, do not seem to fill fissures in the carbonate, but to be of contemporaneous formation with it. These veinules anastomose, but do not commonly intersect, and they vary greatly in their thickness. In weathering, the carbonate of iron yields an abundant ocher, the other carbonates are leached out, and the silica remains as a honeycombed mass, giving rise to exceedingly irregular and fantastic, pitted and cavernous forms, which project ruggedly above the general surface. It is difficult to get a fresh mass of the rock quite free from the yellow ocher. In the least decomposed specimens the carbonates are seen to have the crystalline texture of marble, with a yellowish color. Occasionally there is a bright-green stain apparent in the rock, which may be a silicate of iron.

STRATIGRAPHY AND STRUCTURE.

The stratigraphy of the Franciscan series and the structural or tectonic features, due to disturbances subsequent to the deposition of the beds, can not be adequately discussed in this brief sketch, partly for the reason that the detail necessary for the discussion would be out of keeping with such a general outline, and partly because our information is not yet sufficiently full and exact to permit of a final statement of this aspect of the geology of the peninsula.

As the areal geology is best expressed by properly colored maps, so the relations of the formations of the series to one another may be most effectively and briefly expressed in diagrammatic sections. A number of sections, which are believed to be fairly representative of the general stratigraphy and structure of the series, have been constructed upon carefully plotted profiles, in which the horizontal and vertical scales are the same. These sections are given in Pls. VII and VIII, which will probably be found more useful than lengthy descriptions. A general note will, however, not be amiss. It may be premised that there are many obscure points in the stratigraphy. The identification of horizons in sections which are distant from one another is a matter of extreme difficulty. This arises from the absence of fossils and from the abundance of volcanic formations. These volcanic rocks are in many cases not individually persistent, but have the character of lenses which thin out. There are so many of these lenses at the same and at different horizons, with so little of petrographic characteristic to distinguish them, that confusion is liable to occur. This stratigraphic obscurity is intensified by the general scarcity of bedding planes and the great petrographic uniformity of the San Francisco sandstone. Were these the only formations of the series, the investigation of its stratigraphy would be practically hopeless, save for local sections. There are, however, some horizons of foraminiferal limestone and of radiolarian cherts that have made it possible to obtain results which warrant certain generalizations regarding the sequence of the strata and their structural relations. The base of the series is well exposed in the vicinity of San Pedro Point. Here the basal detrital rocks mantle over the crest of the Montara granite ridge. A little to the north of the ridge, on the slope to San Pedro Valley, the strata are somewhat complexly folded. They have the appearance of having been crowded up against the granite and of having been sharply folded against it. The result has been to throw the strata into anticlines and synclines, some of which have reversed dips. The stratification in this basal formation is more distinct and even than anywhere else in the fragmental portions of the series. As we follow the contact of the series against the granite slopes of Montara Mountain from San Pedro Point southeastward, it becomes apparent that these basal beds have been dropped out of sight by a fault parallel to the axis of the ridge, so that higher and higher horizons of the series come against the granite. If the basal formations of San Pedro Point were all coarse grained, it might be supposed that we had to deal simply with a case of transgression of sediments from northwest to southeast. But a portion of the basal formation is a fine, bluish-black clay-shale. While, therefore, it is possible that a portion of the contact of the granite against higher and higher portions of the series may be due to trangression, it seems more probable that the greater part of it is due to faulting. It is also possible that the rocks classed here as the basal detrital forma-

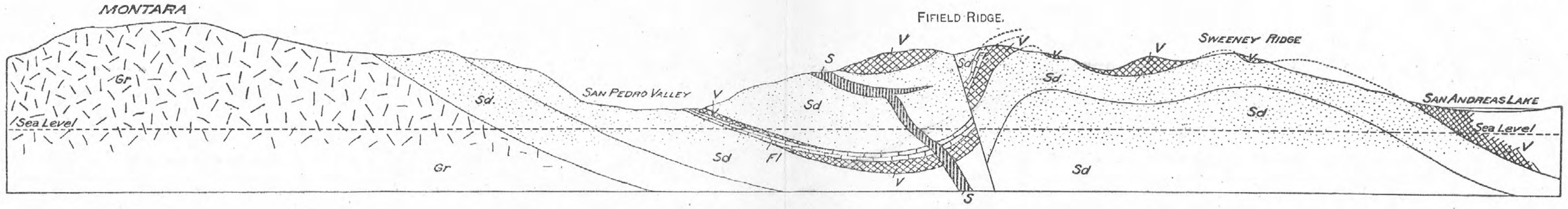


Fig. 1.—Transverse section from the crest of Montara to the middle of San Andreas Lake.

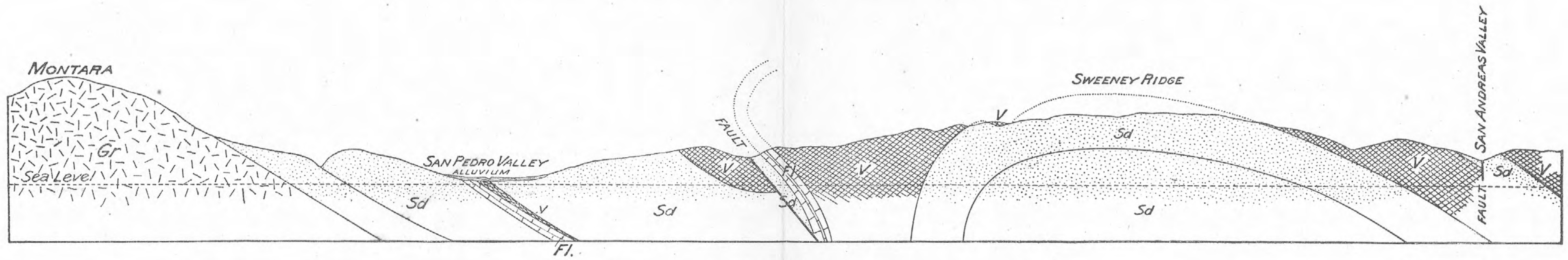


Fig. 2.—Transverse section from the crest of Montara to the north end of San Andreas Valley.

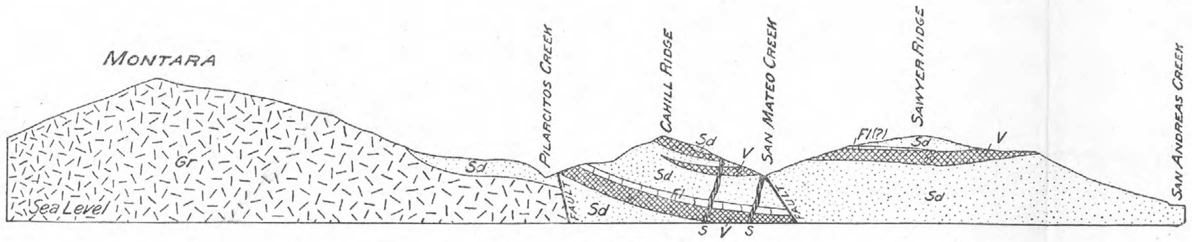


Fig. 3.—Transverse section from the crest of Montara to San Andreas Creek, through a point just below Pilarcitos Dam.

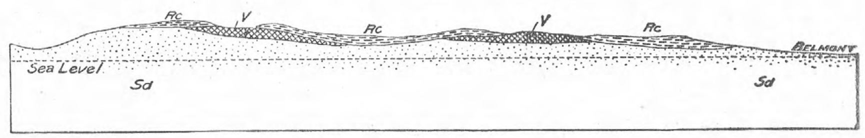


Fig. 5.—Transverse section on north side of Belmont Creek.

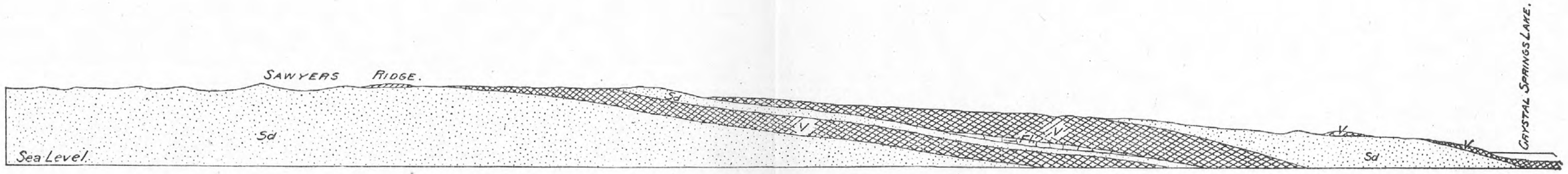


Fig. 4.—Longitudinal section through Sawyers Ridge.

SECTIONS ON SAN FRANCISCO PENINSULA.

Gr, granite; *Sd*, sandstone; *Fl*, foraminiferal limestone; *S*, serpentine; *V*, volcanic; *Rc*, Radiolarian chert.
Scale, horizontal and vertical: 4 inches = 1 mile.

tion of San Pedro Point may be an older series separated from the Franciscan series by an unconformity. This suggestion has little to support it at present beyond the fact that the relations of these rocks to the San Francisco sandstone are not clear, and that the latter very commonly contains fragments of black shale similar to that of San Pedro Point. But whether trangression or unconformity, or both, occur, the fault is present. In Pilarcitos Canyon there is direct evidence of faulting in the discordance of the rocks on either side of the bottom of the narrow ravine, the granite having been dropped out of sight on the northeast side. Farther south, also, the foraminiferal limestone and the volcanic formations, which are known only higher up in the series, are let down so as to abut squarely on the granite. In general, then, it may be safely concluded that there has been an important longitudinal fault between the Montara granite and nearly the entire belt of Franciscan rocks, save for the basal formation, which lies on the granite side of the dislocation, on the south side of San Pedro Valley. The effect of the fault has been that of an upthrust of the granite.

To the northeast of this great boundary fault we have a narrow strip of country lying between Pilarcitos Canyon and its structural extension to San Pedro Valley on the one hand, and Upper San Mateo Canyon and its structural extension to Calera Valley on the other. This strip has a width varying from a little over half a mile to about a mile and a half. It may be recognized on the maps as comprising Cahill Ridge, Spring Valley Ridge, Fifield Ridge, and their extensions out to the coast. This strip has a strike coincident with that of the crest of Montara Mountain. The structure of this narrow strip of country is clearly synclinal, and the sequence of the strata and their tectonic relations can be made out fairly satisfactorily. The base of reference throughout the syncline is the lower of two horizons of foraminiferal limestone which runs through it. This limestone may be traced along the southwest slope of Cahill Ridge at sufficiently close intervals to establish its continuity for the entire distance from about latitude 37° 31′ to Pilarcitos dam. Between latitudes 37° 31′ and 37° 30′ the structure changes somewhat and the outcrop of the limestone crosses the ridge to the northeast side. Along the line of outcrop indicated as far as the dam the limestone reposes upon a sheet of volcanic material of variable thickness up to a maximum of about 200 feet. This volcanic sheet is not persistent for the entire length of the section. It in turn rests on sandstone not less than 600 feet thick. The limestone itself has a maximum thickness of about 100 feet, but is not constant in this respect. In places there are beds of volcanic material and some sandstone between the upper and lower portions of the limestone formation. The limestone is in turn overlain by the sandstone which forms the crest of the ridge. The ridge is parallel with the strike, so that the outcrops of the formations on its flanks are roughly horizontal though undulatory. The dip throughout is into the hill, to the northeast, at low angles.

Beyond Pilarcitos dam the limestone is observable along Spring Valley Ridge, there being an outcrop of half a mile of it, about 100 feet thick, just to the east of Whiting Ridge. Beyond the latter it again presents an outcrop of about a mile on the north side of the upper end of San Pedro Valley. Here it has about the same thickness, and dips into the hill beneath a sheet of volcanic rock. Beyond this it passes beneath the alluvium of San Pedro Valley.

The other limb of this synclinal trough of limestone is exposed on the slopes of San Mateo Canyon. From Crystal Springs Lake to the vicinity of Pilarcitos Lake the croppings are difficult to observe; but here, again, they have been found at sufficiently close intervals to establish beyond question the presence of the limestone band in practical geological continuity. Where the dip is observable it is into the hill toward the southwest. On the lower flanks of Fifield Ridge the exposure is more definite, and the outcrops are continuous for about two miles, with constant dips into the hill. It is then cut off by the fault which follows San Mateo Canyon. After a short interval it crops out again strongly, with clearly revealed, steep, southerly dip, striking over the divide between San Mateo and San Pedro drainages. Beyond this it is traceable for three-quarters of a mile in isolated croppings. It is next observed clearly exposed for over a mile, striking across the ridge between the two northern branches of San Pedro Creek. Here, however, the dip is reversed. This limb of the syncline which, as we have passed westward, has been acquiring a steeper dip, has at last been bent over so as to present a reversed dip. This reversed dip continues out to the coast and is well seen on the headland on the north side of Calera Valley. The bottom of the syncline is well exposed, resting on the apex of a hill which overlooks both Calera and San Pedro valleys.

The establishment of this syncline is one of the most important results of our mapping, and affords us the key to the true sequence of the strata and to the general structure of this portion of the Franciscan series. Using this as a reference plane and consulting the diagrammatic sections we may observe that the sequence is not in all localities the same, the presence of sheets of volcanic rock being variable. It is clear, however, that it separates the sandstones into at least two great divisions, one below the limestone horizon and the other above it. The volcanic sheets or lenses, being of local or accidental occurrence in either division, may be regarded simply as temporary interruptions to the sedimentation. This is the most important generalization which can be made regarding the stratigraphy of this lower portion of the series. More detailed subdivisions of the sandstone, on petrographic or stratigraphic or paleontologic grounds, are scarcely to be hoped for in this field. The result arrived at carries with it an important rider, to the effect that the structure of the series is essentially simple. Although folded and faulted, the folds are not involved or intricate,

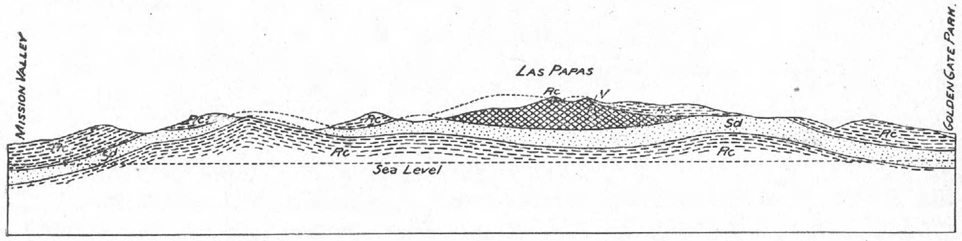


Fig. 1.—Northwest and southeast section (parallel to strike) through Las Papas Ridge from Mission Valley to Golden Gate Park.

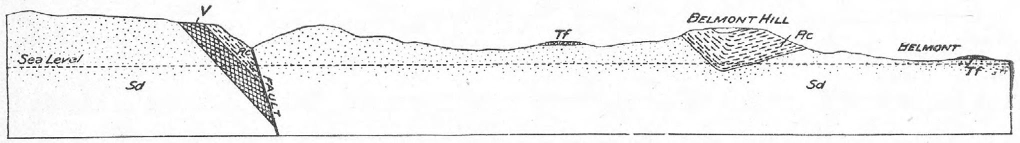


Fig. 2.—Transverse section on south side of Belmont Creek.

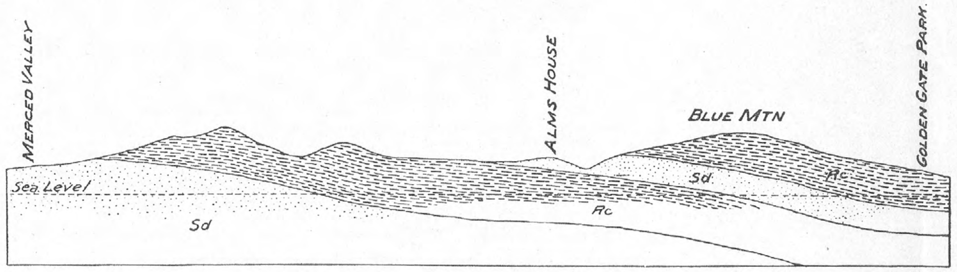


Fig. 3.—North and south section through the Alms House, from Merced Valley to Golden Gate Park.

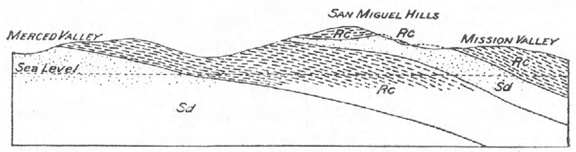


Fig 4.—Northeast and southeast section from Merced Valley to Mission Valley, through San Miguel Hills.

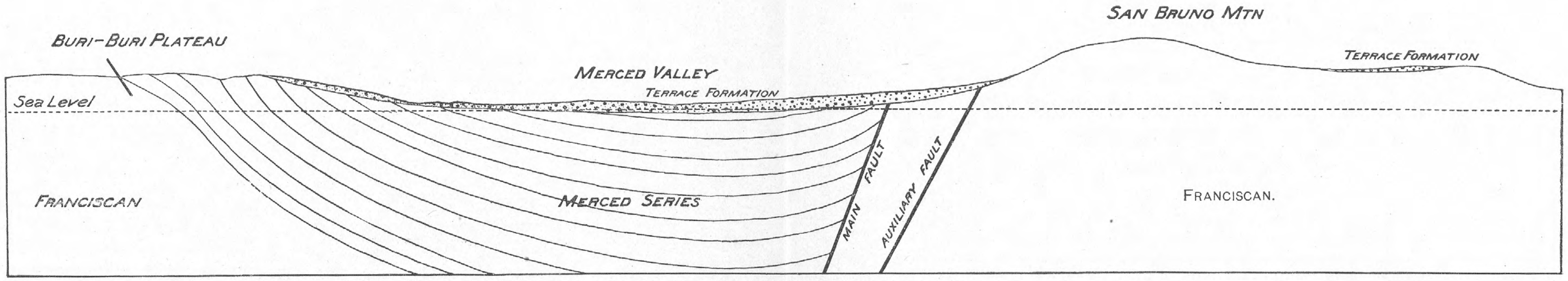


Fig. 5.—Transverse section from Buri-buri Plateau to San Bruno Mountain, across Merced Valley, to show interpretation of the structure.

SECTIONS ON SAN FRANCISCO PENINSULA.

Sd, sandstone; *Rc*, Radiolarian chert; *V*, volcanic; *Tf*, terrace formations (gravels).

Scale, horizontal and vertical: 4 inches = 1 mile.

and the faults, as will be seen later, are in accordance with a definite system.

Beyond the dominant syncline of the Franciscan belt which flanks Montara we have, running parallel with it, a great fault which follows the line of outcrop of the outer limb of the limestone syncline, as above sketched, along San Mateo Canyon to its head, and thence across the divide to the coast through the south branch of Calera Valley. This is a reversed fault in its western portion, and probably during its entire extent, so that we have an overthrust of the strata to the northeast over those to the southwest of the fault plane. It is this fault which has effected the dislocation of the inverted portion of the syncline as illustrated in two of the general sections (Pl. VII, figs. 1 and 2). The strip of the general Franciscan belt which lies between this fault and San Andreas Valley, comprising Sawyer Ridge and Sweeney Ridge, is an anticlinal fold. The dip is in general so low and undulatory, however, that this structure is, for the most part, not locally observable. Only the lower division of the sandstone is in general represented in it, the upper division and the separating limestone formation having been removed by the truncation of the arch of the anticline, except at the southern end of Sawyer Ridge. The general transverse sections (Pl. VII, figs. 1, 2, and 3) illustrate the structure of this ridge, and the longitudinal section (Pl. VII, fig. 4) through its axis shows the simplicity of its stratigraphy. This simplicity is also apparent on the cuttings of the wagon road from San Andreas dam to the summit of the ridge. It is here evident that, although the bedding planes undulate and are subject to minor disturbances, the strata are not folded or inclined at high angles. This anticlinal strip is in turn bounded by a remarkably straight fault which has conditioned the San Andreas and Crystal Springs Valley, one of the most noteworthy features of the topography. The valley bounds Buri-buri Ridge on the southwest. This fault line appears to be the trace of a normal fault with a pronounced downthrow on the northeast side. The effect of this downthrow has been to let down beside the lower division of the sandstone the higher portion of the upper division, which is characterized by the presence of radiolarian cherts and by intrusive sheets and lenses of peridotite serpentine.

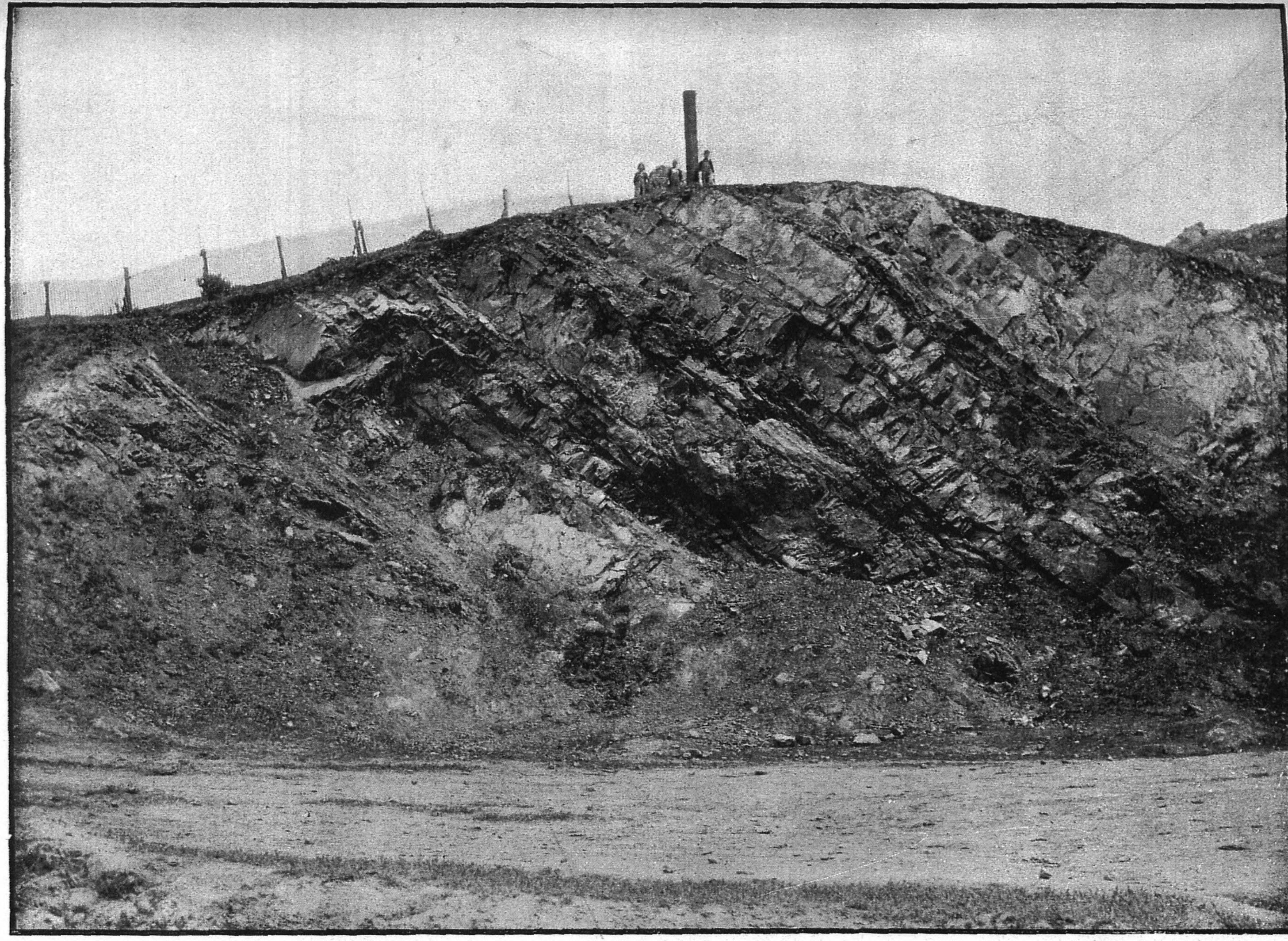
The general structure of the Franciscan strata in this portion of the belt is not so clear as in the syncline and anticline above referred to, but all the evidence available points to a generally undulatory attitude of the rocks, with no pronounced folds or faults save of a local or nonpersistent character. The two diagram sections, one on either side of Belmont Creek, illustrate fairly well the two extremes of structure exhibited in this belt. On the south side of the canyon the strata are sharply compressed, folded, and faulted (Pl. VIII, fig. 2). This, however, is quite local, for just across the canyon to the north the strata are practically flat, with gentle undulatory dips (Pl. VII, fig. 5). The latter condition is the more prevalent in this outer portion of the belt.

The most important stratigraphic feature of Buri-buri Ridge and of the hills between Crystal Springs Lake and Belmont is the presence of the radiolarian cherts. The largest development of these rocks is on the hills on either side of Belmont Creek, as shown in the two sections just referred to. The great majority of individual occurrences of these cherts along Buri-buri Ridge, Las Pulgas Ridge, and the neighboring hills take the form of very limited patches, which are usually scarcely possible of representation in the geological mapping. They are in several cases clearly interbedded with sandstone, and it is probable that such was the original condition of all of them. Most of them are now found resting on the surface of the sandstone, the overlying formations having been removed. A few of the patches on Buri-buri Ridge rest on the serpentine or on the volcanic formations. There are about fifty of such patches on Buri-buri Ridge. Not more than five of these have an area of over 10 acres, and a great majority are less than an acre or two in extent. It is quite clear that they do not all occur at one horizon, but are distributed through the sandstone vertically as well as horizontally. They are usually from 10 to 50 feet thick. Considering that the formation is one of the most resistant to weathering forces in this field, there seems to be no possibility of regarding these patches of chert as residual portions of persistent and continuous sheets. They are, and may be observed to be, local deposits of very limited horizontal extent. This, however, is but one phase of the occurrence of these cherts. In the vicinity of the city of San Francisco far more voluminous and persistent deposits of these rocks are met with, which are also, probably, local lenses of greater dimensions.

Another important stratigraphic feature of Buri-buri Ridge and of the hills to the south, between Crystal Springs Lake and Belmont, is the diminution in the volume of the volcanic rocks. The volcanic sheets occur in thinner and less persistent beds. At this stage of the accumulation of the series, volcanic activity seems to have been on the wane, and the accumulation of the cherts to have been initiated. It seems, therefore, not improbable, in view of the discussion on a previous page as to the nature of the radiolarian cherts, that much of the silica which enters into their composition is of submarine, solfataric origin.

The structural features of Buri-buri Ridge, which are due to the presence of intrusive lenses of peridotite-serpentine, are described sufficiently for the present under the discussion of the serpentines.

Before closing this brief outline of the salient tectonic features of this belt of the Franciscan series, it may be well to observe that the period of disturbance of the strata is unknown. The most of it seems to have long antedated the uptilting of the Montara fault block, so that the latter differs from most tilted blocks with which we are familiar. These are commonly tilted blocks of strata previously undisturbed, and the tilting is recognizable by the attitude of the strata and the



STRATIFICATION OF SAN FRANCISCO SANDSTONE, NORTHWEST END OF SAN BRUNO MOUNTAIN.

presence of the fault scarp. In the present case, however, the region had been moderately folded and profoundly faulted, with local sharp plication, and the whole had probably been reduced to a peneplain and buried by newer rocks before the occurrence of the tilt, which is the controlling feature in the present geomorphy. It seems not improbable that there was movement on the San Andreas fault at the time of the deformation of the Merced series, and this must have been closely coincident with the uptilt of the block.

Passing now to the northern portion of the Franciscan terrane, i. e., that portion lying between Merced Valley and the Golden Gate, we find that here, also, the general features of the stratigraphy and structure are simple, although frequently complex in detail. A large amount of this complexity of detail appears to be due to the presence of the radiolarian cherts in considerable volume. These are exceedingly hard and brittle rocks, but they are thin-bedded and have plastic partings between the beds. This physical structure enables them to fold easily under compression, with endless minor fracturing of the hard beds. We have thus in these rocks many local contortions and folds of great complexity. These, however, do not affect the general structure of the series, and for the present they are ignored.

The general structure of San Bruno Mountain is that of a great volume of sandstone, with subordinate beds of shale, dipping to the northeast at low angles. The angle of dip varies, but is usually low, rarely exceeding 45°. Within this general structure there are a few minor folds in which, by the development of synclines and anticlines, the dip is locally to the southwest (Pl. IX.) The bold scarp-like southwest front of the mountain is a fault scarp, somewhat degraded; and besides the main fault it is probable that there is an auxiliary fault by which the line of shoulders and parallel ridges which buttress the mountain have been let down against its face at the time of the general tilt.

The strata of San Bruno Mountain, having a visible thickness of over 1,500 feet, and doubtless corresponding to the sandstone of Sawyer and Sweeney ridges, appear from the general dip to pass under the entire northern end of the peninsula. The dip is continuous throughout the Las Papas group of hills in the center of the city of San Francisco. Three profile sections are given through these hills, two transverse to the strike, and one parallel to it (Pl. VIII, figs. 1, 3, and 4). From these sections it is apparent that as we ascend the series above the sandstone of San Bruno Mountain we come in succession upon two distinct horizons of radiolarian cherts, with an intermediate formation of sandstone separating them. Above this intermediate formation of sandstone, and between it and the upper cherts, is a local lens of volcanic rock which forms the mass of Las Papas Ridge proper. The sections in these hills are exceptionally clear, and the relative attitudes of the strata and their relative volumes are well revealed as they are indicated in the section. To the northeast of these cherty hills, i. e., in the direction of the dip, we have a belt of serpentine which is described elsewhere as extending from Fort Point to Hunters Point, its general trend being parallel to the strike of the strata, and its stratigraphic position, in so far as it can be said to have any, being above the principal horizon of the cherts. It is probable that these serpentines have been dropped to their present position by a fault which traverses the peninsula from the vicinity of Fort Point to the southward of Hunters Point. Still farther to the northeast we have again sandstones which in part underlie the serpentine. Their relations are much obscured by sand dunes.

As regards the volume of the strata which make up the Franciscan series, the only information that can be given at present is contained in the sections, which are made true to scale.

CORRELATION.

The Franciscan series is of Mesozoic age and belongs with great probability to either the Cretaceous or Jurassic. Both Whitney and Becker have referred the formations comprised in the series to the Cretaceous. Whitney's warrant for this reference was a slight one, and consisted of a single specimen of an Inoceramus, found in the San Francisco sandstone of Alcatraz Island. This find was held with great confidence to establish the Cretaceous age of the San Francisco sandstone and its associated formations. Becker assumed that these rocks were the equivalent of the fossiliferous Knoxville beds, and therefore of Lower Cretaceous age. This correlation has not yet been established. Fairbanks has combatted the common view of Whitney and Becker, and has pronounced the series to be of pre-Cretaceous age. He has not yet, in the writer's opinion, established the correctness of his contention.

When the investigation of the San Francisco Peninsula was undertaken, it was confidently expected that enough fossils would be found to satisfactorily determine the geological age of the series. This expectation the writer has not realized, for, although a few fossils have been found, they still leave the correlation of the series an open question. It is this uncertainty which has necessitated the introduction of a local name for the series. The Franciscan series has strongly marked characteristics throughout the Coast Ranges, and it may be investigated and its relations to other series discussed independently of its geological age. Its correlation may therefore be deferred till we have a fuller knowledge of its fossil fauna.

A few notes as to the fossils which have been found are here given as a contribution to the data upon which the correlation of the series must eventually be based. In a pebbly sandstone, containing very numerous fragments of black shale, a fragment of the cast of a shell was found in a canyon at a point 2¾ miles due south of San Mateo Station. The fragment was pronounced by Mr. Stanton, to whom it was submitted, to be either an Inoceramus or an Aucella. The locality was carefully and patiently examined by three interested observers, but no other fossils or fragments of fossils were found. The evidence, such as it is, points to the Jurassic or Cretaceous age of the sandstone.

On the northeast slope of Montara Mountain, on the crest of Whiting Ridge, a number of imperfect fossils were found which are of especial interest because of their occurrence near the base of the series, where it reposes upon the granite. The matrix in which they occur is sandstone. These fossils were submitted to Mr. Stanton, who kindly prepared the following statement concerning them:

The fossils are nearly all casts of small Lamellibranchia, usually showing none of the features of the external surface and so few of their other characteristics that most of them can not be determined even generically. Several specimens, however, that retain impressions of the hinge, belong to the Arcadæ, and some of these seem referable to Pectunculus, a genus that ranges from Lower Cretaceous to the present time. One small, imperfect cast has the form of an Opis, and if we could be certain that it is that genus it would fix the age as Mesozoic, with the probabilities in favor of Lower Cretaceous or Jurassic. On the other hand, there is a fragment showing the imprint of a small part of the surface of a shell that, in its ornamentation, is very much like some of the late Tertiary and recent species of Venus. These notes are sufficient to show that there are no characteristic forms recognizable in the collection that are decisive of its Mesozoic or Cenozoic age. There is nothing among them that suggests the Paleozoic.

It is hoped that these beds may yield to future search some better-preserved forms which will decide their age.

The foraminiferal limestone was first discovered to be fossiliferous by an inspection of the wave-polished surface of the rock which forms the headland on the north side of Calera Valley. Here, with the unaided eye, numerous spots were detected, and under the lens these were in many cases seen to be chambered shells. The Foraminifera were afterwards observed in similar limestone from various localities. A series of sections were prepared and were submitted to Mr. Charles Schuchert for examination. The following is his statement regarding them:

The limestone from the crest of Fifield Ridge, from the headland on the north side of Calera Valley on the coast, and from Crystal Springs Lake contain an abundance of Foraminifera, all apparently of the family Globigerinidæ. The genera Orbulina, Globigerina, Textularia, and Rotalia seem to be present. The limestone from the north side of San Pedro Valley may have organic remains. If what I see are Foraminifera, then the genus Orbulina seems to be indicated. Because of the abundance of Foraminifera it seems to be more reasonable to suppose the age of the limestones to be Mesozoic or Cenozoic rather than Paleozoic.

Referring to these same sections Professor Walcott kindly added the following note:

It is seldom possible to determine Foraminifera in such sections more closely than by genera, and as many of the species of these low forms have continued unchanged from the Cretaceous to the present day, it is evident that the age of the formation can not be definitely determined from such specimens in the absence of other fossils. I think that in this case the association of forms indicates an age not earlier than the Cretaceous.

The only other fossils which have been discovered are the Radiolaria of the radiolarian cherts. The obscure remains of these forms may commonly be detected in the cherts with the aid of a lens as minute round dots. A number of sections were made of what was deemed the most promising material, and of these the best, which proved to be from Buri-buri Ridge and from Angel Island (the latter found by Mr. F. L. Ransome), together with chips of the rock, were sent to Dr. George J. Hinde, the well-known authority on these forms, who kindly consented to examine them. The Angel Island cherts proved to be the most prolific and to have better-preserved forms. Mr. Ransome having in preparation a monograph on the geology of Angel Island, which is to appear shortly after the date of this writing, Dr. Hinde's note is published therewith, the interest attaching to it demanding as early a publication as possible. For the full note with the accompanying figures Mr. Ransome's paper[1] must be consulted. The locality from which the chert was taken on Buri-buri Ridge was about a mile to the southeast of San Andreas dam. Dr. Hinde's list of the forms identified by him from Buri-buri Ridge is here given, together with those occurring on Angel Island, which, geologically, is but a continuation across the Golden Gate of the Franciscan terrane of the San Francisco Peninsula:

RADIOLARIA.

Suborder.	Genus.	Locality.
Sphæroidea, Hæckel	Cenosphæra, Ehrenberg	Buri-buri Ridge and Angel Island.
	Carposphæra, Hæckel	Buri-buri Ridge.
Primoidea, Hæckel	Cenellipsis, Hæckel	Buri-buri Ridge and Angel Island.
	Ellipsidium, Hæckel	Angel Island.
	Lithapium, Hæckel	Do.
Discoidea, Hæckel	Tripocyclia, Rüst	Do.
	Hagiastrum, Hæckel	Do.
Cyrtoidea, Hæckel	Dictyomitra, Zittel	Buri-buri Ridge and Angel Island.
	Lithocampe, Ehrenberg	Buri-buri Ridge.
	Sethocapsa, Hæckel	Angel Island.

In his note Dr. Hinde calls attention to the similarity of these forms to cherts of Jurassic and Cretaceous age from the Tyrol, Switzerland, Hungary, and other places.

SERPENTINE.

OCCURRENCE.

Associated with the rocks of the Franciscan series are many masses of serpentine, which in the aggregate form an important proportion of the area occupied by this terrane. In all cases where the evidence from the mode of occurrence is clear, or even suggestive, it points to an instrusive relation between the serpentine and the sandstone or other formations of the Franciscan series. The masses have, in the great majority of cases, the characters of laccolites, instrusive sills, or dikes.

[1] Bull. Dept. Geol. Univ. Cal., vol. 1. No. 7.

The greater part of these serpentine masses are grouped in three linear tracts which traverse the peninsula from northwest to southeast, conformably with the general strike of the country. One of these tracts lies in the northern portion of the Franciscan terrane, i. e., to the north of Merced Valley, and the other two in the southern portion. That lying in the northern portion of the terrane extends from Fort Point, on the Golden Gate, to the extremity of Hunters Point, on the bay. It has thus a length of about 10 miles, and is, at its maximum exposure, about 1½ miles wide. This belt is probably continuously or nearly continuously occupied by serpentine, although this supposition can not be verified by observation, owing to the mantle of sand and alluvium which conceals parts of the rocky surface. Sufficiently large areas are unobscured and are sufficiently close together, as may be seen by consulting the map, to warrant the belief that the formation was once geologically continuous, although remnants of the overlying sandstone into which it is intrusive, or exposed portions of the floor upon which the sheets rest, may effect a superficial segregation into distinct areas. While this continuity may be fairly assumed, it is clear from the exposed portions of the belt that it is interlocked in an irregular way with the sedimentary formations of the series, and that the configuration of the belt actually occupied by serpentine is by no means simple. Similar statements may be made with reference to the second dominant belt of serpentine. This occupies the southeastern portion of Buri-buri Ridge from San Andreas Lake to San Mateo Creek, and nearly the whole of Las Pulgas Ridge. The total length is about 11½ miles, and the maximum width of the belt is little over 1 mile. The exposure of the serpentine of this belt is practically unobscured by any mantle of sand or alluvium, and the actual area occupied by it may be precisely delineated. The mapping of the serpentine shows that it is not a strictly continuous formation, but that it takes the form of masses having in general an intricate boundary against the formations of the Franciscan series. Some of these masses are clearly geologically continuous with neighboring bodies of serpentine, though separated at the surface of the ground by intervening areas of other rocks. Other bodies of serpentine are clearly geologically discontinuous and form individual masses which, of course, are doubtless genetically connected. These increase in the extent of their exposure as we pass along the belt southeastward. In the vicinity of San Andreas dam the ridge is composed chiefly of rocks of the Franciscan series, with a subordinate proportion of serpentine appearing in irregular areas in their midst. Toward the end of the ridge at San Mateo Creek the serpentine dominates and the rocks of the Franciscan series appear in irregular areas in the midst of the serpentine; while on Las Pulgas Ridge the dominance of the serpentine is still more pronounced. A glance at Pl. V will make clear the relative distribution of the serpentine and the Franciscan rocks. Notwithstanding the intricate areal relations brought out by the mapping of the ridge, there has nowhere been observed any evidence or suggestion of evidence of the gradation of the serpentine into the rocks with which it is associated.

The third belt of serpentine consists of a linear group of dike-like masses distributed along San Mateo Canyon between Sawyer and Cahill ridges, on the pass between Cahill and Fifield ridges, and thence obliquely along Fifield Ridge and across San Pedro Valley nearly to the ocean. There is also a small mass on Spring Valley Ridge. The total linear extent of this belt of occurrences is 6 miles. Generally the dikes are narrow relatively to their lengths, and they traverse the country in directions which are inclined to the strike, and in some cases the dip of the dikes is nearly normal to the dip of the strata which they intersect. One of these dikes is traceable for 2 miles on Fifield Ridge, with only a single gap of a few hundred feet. Its average width is about 300 feet. Another, just at the pass, has a length of nearly a quarter of a mile and a width of about 150 feet. The patch of serpentine on the crest of the ridge, about three-eighths of a mile to the southeast of the pass, is probably the remnant of an intrusive sheet. The other occurrences, on the slopes of San Mateo Canyon, are too much obscured by brush to permit of any positive statement concerning them, except that their linear disposition—oblique to the strike of the strata—and their small width suggest that they, also, are dikes. The northwestward extension of this group is somewhat scattering, like that of the southeastward in San Mateo Canyon, but the occurrences are more definitely known as to extent. There are two small outcrops on the lower slopes of the northeast branch of San Pedro Valley and three others at the head of the middle branch of the same valley. There is also a small protrusion of serpentine on a spur of the south side of Calera Valley.

Of the more sporadic outcrops not referable to these three belts may be mentioned two near the bottom of the cirque-like canyon a little over half a mile northeast of San Mateo poor farm, and another—a small outcrop—on the southwestern edge of the canyon above the reservoir on Belmont Creek, south of the wagon road. There is a small patch on the western brow of a hill 2 miles due west of Belmont station. A small dike of serpentine intersects the wagon road from San Andreas to Pilarcitos, about 200 yards west of the summit of Sawyer Ridge. On the south side of the Golden Gate, within a mile and a half of Point Lobos, and east of it, there are three small patches of serpentine, none being more than a few acres in extent. One of them is clearly a dike. On the south side of San Bruno Point a small patch is exposed in the sea-cliff. On the crest and northerly slope of the ridge to the north of Visitacion Valley are three small patches. On the southwest slope of San Bruno Mountain and on the shore at Mussel Rock a few bowlders of serpentine have been found.

PETROGRAPHY.

The range of petrographical variation of the serpentine appears to be fairly constant in all of its occurrences throughout the peninsula. The various conditions and aspects assumed by the rock are functions of a process of chemical alteration from a peridotite or pyroxenite and of a mechanical disintegration of the rock thus altered. The original peridotite seems to have been essentially the same in all cases. In no case has the peridotite been found in its original condition free from the products of serpentinization. Its characteristics may nevertheles be established with certainty. The least-altered form of the serpentine presents the characters of a rock having a dense, dark brownish-green, fairly homogeneous groundmass, in which are embedded numerous lustrous crystals of lamellar pyroxenes. This form is found occasionally in large masses devoid of any notable shearing planes, but more commonly it occurs in the form of very numerous well-rounded bowlders, of which the serpentine masses are largely composed. These bowlders lie, sometimes closely packed, sometimes sporadically, in a body of rock which has evidently been profoundly sheared by differential movements within the mass. The shearing action has developed planes of movement in all possible directions throughout the mass. On these planes slickenside phenomena are often apparent. They are commonly coated with gleaming films of carbonate and silicate of magnesia. Even where the evidence of slickensiding is absent, as in small fragments, it is impossible to secure a hand specimen whose form will not be conditioned by smooth glossy planes of parting which are developed by every effective blow of the hammer. Under the influence of the weather this slickensided variety of the rock breaks down in a very friable, soft, bleached greenish-blue shale. This shale gives rise to no soil and is usually comparatively bare of vegetation. The massive phase, when in sufficiently large bodies and not in the bowlder form, does not break down under the influences of the weather, but develops roughly irregular and even ragged surfaces, generally devoid of any sedentary soil. It is very commonly traversed by a network of thin sheets or veins of silky chrysotile, and of less fibrous, yellowish-white varieties of vein serpentine. These rarely exceed one-quarter of an inch in thickness, and usually they are very much thinner. The slickensided facies occasionally grades into a condition which may locally be regarded as roughly fibrous. In the various occurrences which have come under observation all possible gradations have been found from bodies of considerable extent, which are perfectly massive in aspect, and rich in lamellar pyroxenes, through conditions where the massive bowlders are large with a relatively small proportion of slickensided material, to conditions where the latter predominates and the bowlders are small, more lens-like, and widely separated. In the most disintegrated form bowlders are in some cases found only after patient search.

The field evidence leaves no doubt whatever that the most shaly variety of the serpentine is derived from the massive form by process of disintegration. Any inquiry as to the original rock from which the serpentine in general is derived must therefore be directed to the massive form. The essential features of this form are so constant that it has not been thought necessary to subject specimens from more than one locality to rigid microscopic investigation. The occurrence selected for this study was the mass which is so well exposed in the Potrero district of the city of San Francisco. The work of investigation was assigned to Mr. Charles Palache, who, as a graduate student at the University of California, energetically assisted the writer in the elucidation of the geology of the peninsula. Mr. Palache's studies were conducted under the supervision of the writer and his results have already been published.[1] For a detailed account of this typical mass of serpentine his paper must be consulted. A few of the leading facts are here quoted from his description of the microscopic character of the freshest material obtained by him.

Under the microscope serpentine is seen to be the predominating mineral. Embedded in it are numerous pyroxene crystals of varying dimensions, less abundant grains of olivine and grains of chromite and magnetite.

The serpentine is colorless in most sections, but in some it has a slight tinge of green. Its structure is not apparent in ordinary light, but with crossed nicols it is seen to be a colorless felted aggregate, too fine to be studied as individuals with the microscope. The serpentine aggregate exhibits weak double refraction, the interference colors never surpassing a pale yellow, and being more commonly tints of gray. Between crossed nicols it retains nearly the same tint throughout a complete revolution of the stage, owing to compensatory extinction of the irregularly oriented serpentine fibers. While a large proportion of the serpentine is thus lacking in any definite arrangement of the component fibers, in places narrow bands in which the fibers are approximately parallel are seen to inclose areas of confused orientation. By their mode of arrangement these bands give rise to two well-known types of structure: The "grating" structure and the "mesh" structure. The grating structure is characteristic of areas of serpentine derived from enstatite and diallage. In it the bands of parallel fibers are in parallel position corresponding to the direction of the dominant cleavage in the original mineral. The fibers are at right angles to the bands. The mesh structure is found in areas of serpentine derived from olivine. In this structure the bands intersect somewhat irregularly, but generally in rectangular positions surrounding eye-like areas of felted serpentine. The bands are frequently marked by a concentration of limonite and magnetite along their course in both types of structure. Experiments made on several thin sections of serpentine proved that it was readily gelatinized by both hydrochloric and sulphuric acid.

The pyroxene is of two kinds—an orthorhombic variety with the characters of enstatite, and a monoclinic pyroxene, determined as diallage. The enstatite, which is by far the more abundant of the two, occurs in large individuals, which are very noticeable in hand specimens of the rock, the brilliant cleavage faces causing them to stand out prominently from the dull green of the surrounding serpentine. Though apparently porphyritic in character, these individuals have in no case crystal boundaries, but are remnants of an originally coarse allotriomorphic-granular rock which have escaped the serpentinization affecting most of the mass. In thin section it is

[1] The Lherzolite-Serpentine and Associated Rocks of the Potrero, San Francisco. Bull. Dept. Geol. Univ. Cal., vol. 1, No. 5.

colorless and presents one dominant cleavage parallel to the brachypinacoid. The prismatic cleavage may be recognized in basal sections, but is feebly developed. The interference colors are low, varying from pale green to yellowish gray, in this respect presenting a marked contrast to the diallage found in the same slide. Cleavage fragments exhibit parallel extinction, and plates parallel to the pinacoidal cleavage show no optical figure—features which prove its orthorhombic character. Many of the enstatite crystals exhibit the effect of pressure or shearing force in the bent and twisted condition of their cleavage laminæ, resulting in an undulatory extinction between crossed nicols. The source of this stress probably lies in the increase in bulk of the rock, resulting from the hydration and serpentinization of the minerals composing it.

The process of serpentinization, before referred to, may be observed in all stages of development, both as to individual crystals of enstatite and as to the mass of the rock. In the enstatite the change begins along the cleavage planes, gradually extending in all directions until the whole mass of the crystal is involved. The structure of the enstatite is so well retained, however, that frequently the change can only be detected by the use of polarized light, which reveals the more or less complete substitution of the serpentine aggregate for the original mineral. The change is sometimes, but not always, accompanied by the deposition of hydrous iron oxide along the cleavage cracks, the result of which is to emphasize the original structure of the enstatite as seen in the grating structure of the serpentine before mentioned.

Diallage is present in quite a subordinate amount in the slides of this rock which were studied. As, however, the diallage changes to a serpentine indistinguishable from that derived from enstatite, and as a large proportion of this rock has undergone serpentinization, it is impossible to ascertain what was the ratio of the pyroxenes in the original rock. Diallage occurs in irregularly bounded grains of varying size. It is colorless and may be recognized, even in ordinary light, by the perfection of the orthopinacoidal cleavage. A more characteristic feature is the appearance of high interference colors between crossed nicols and the rough surface seen in convergent light. The extinction is inclined, the maximum angle on the trace of the orthopinacoidal cleavage being 38°. Besides the orthopinacoidal cleavage there is a well-marked prismatic cleavage seen on basal sections. No case of intergrowth between diallage and enstatite was observed, though the two minerals are frequently developed side by side. The diallage exhibits the same pressure effects as does the enstatite, and its decomposition into serpentine was observed in various stages of completeness and offers no points of difference from that of the orthorhombic pyróxene.

Olivine is present in only a portion of the slides which were prepared from this rock, and where present is in small amount. The ease with which olivine is changed to serpentine is, however, well known, and it may well be assumed that it would be the first constituent of the rock to undergo decomposition. As much of this rock has been serpentinized, it is easily possible that olivine may have been originally an abundant constituent, but it is now almost wholly removed by differential decomposition.

The olivine occurs only in very small grains or fragments embedded in serpentine. The fragments usually have a common orientation over considerable areas, showing the olivine to have originally formed individuals of large dimensions. It is colorless and has the rough shagreened surface characteristic of olivine, so that it stands out strongly from the surrounding serpentine. It exhibits no trace of cleavage, and as the boundaries of the grains are wholly irregular, no observations for extinction were obtained. The interference colors are very brilliant. Some difficulty was found in distinguishing olivine from certain sections of diallage, but the following characteristics seem to clearly separate them: As the olivine exhibits no cleavage, sections without cleavage may, of course, be found which show no interference figure in convergent polarized light; but sections of diallage parallel to the orthopinacoid, which, as the prismatic cleavage is frequently not apparent, would exhibit no cleavage, are at right angles to the plane of the optic axis, and hence must show the emergence of either an optic axis or a bisectrix. As this is the only section of diallage in which cleavage is not visible, it may thus be distinguished from olivine. The alteration of olivine to serpentine takes place in the manner described by so many authors. The meshes of the resultant serpentine frequently contain at their centers residual grains of olivine, and magnetite is abundant in the cracks, as well as limonite.

Chromite occurs in scattered, irregular grains embedded in the serpentine, but not, so far as observed, included in the original constituent of the rock. It exhibits the characteristic high relief and dark-brown color of chromite, and gives a strong reaction for chromium in a borax bead. Magnetite is found in irregular grains and in octahedral crystals, mostly occupying veins and cracks in the serpentine, but also occurring as inclusions in the orignal minerals of the rock. No feldspar, nor any mineral or aggregate which could be referred to feldspar for its origin, could be discovered in any phase of the rock.

The evidence thus presented proves that the serpentine is derived from a crystalline rock whose original constituents were olivine, enstatite, diallage, chromite, and magnetite. It thus has the composition of a lherzolite, and is accordingly so designated.

Two analyses are on record which throw light upon the chemical composition of the serpentines of this field, one by Dr. J. D. Easter, on the serpentine of the city of San Francisco, quoted by Newberry,[1] and a recent one by Mr. F. Leslie Ransome, on the serpentine of Angel Island.[2]

	I. San Francisco.	II. Angel Island.
SiO_2	39.60	42.06
Cr_2O_3	.20	
Al_2O_3	1.94	$Al_2O_3+FeO_3$ 2.72
FeO+MnO	8.45	FeO 2.88
MgO	36.90	39.53
H_2O	12.91	12.04
	100	99.23
Sp. g.	....	2.61

TECTONIC RELATIONS.

In the foregoing pages it is apparent, from the preliminary consideration of the areal distribution of the serpentine, and from the detailed microscopic study by Mr. Palache of a typical occurrence of it, that the rock is of irruptive origin; and this conclusion is confirmed by the more recent work of Mr. Ransome on Angel Island, which becomes available as the present paper goes to press. A more critical inquiry into the relations of the chief serpentine masses to the strata of the Franciscan series is entirely confirmatory of this conclusion.

THE PRESIDIO LACCOLITE.

The relations of the serpentine to the San Francisco sandstone are clearly revealed in fine cliff section in the vicinity of Fort Point on the

[1] Pacific Railway Reports, Vol. VI, Pt. II, p. 11, 1855.
[2] Bull. Dept. Geol. Univ. Cal., Vol. 1, No. 7, p. 231.

Golden Gate. (See fig. 6.) Here it is very evident that the great mass of serpentine which is exposed in the sea-cliffs to the east and west of the point rests upon a sheet of sandstone having a thickness of about 160 feet. With this sandstone there are subordinate beds of shale, and a small lens of basic volcanic rock. This sandstone sheet is nearly flat in its attitude, but is undulating and disturbed in detail, and has apparently a general low dip to the southeast. The serpentine which rests upon it is clearly a laccolite or laccolitic sill. It will for convenience be referred to as the Presidio laccolite. The contact of the two formations, i. e., the bottom of the serpentine, where it reposes on the sandstone, may for short distances be traced out and carefully examined with knife-edge precision in the face of the cliff on the outer side of Fort Point. This favorable section shows that the serpentine bears an intrusive relation to the sandstone, the evidence being the alteration of sandstone to a hard compact hornfels at the contact and the inclusion in the serpentine of occasional angular fragments of the sandstone in an altered condition. The upper arch, or roof, of the laccolite has for the most part been removed by denudation, and the portions which remain are more or less obscured by the blown sand which mantles the region. To the southeast of Fort Point areas of the serpentine project

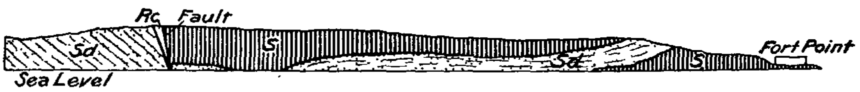


FIG. 6.—Meridional section through Presidio laccolite, Fort Point. *Sd* = Sandstone, *S* = Serpentine, *Rc* = Radiolarian chert. Scale, horizontal and vertical: $\frac{1}{7500}$.

in sufficient abundance through the sand to demonstrate that it extends continuously to the Mission Valley near the head of Market street, a distance of about 4½ miles. For about half of this distance the base of the laccolitic sill on the northeast side may be fairly well traced out as it is mapped, and may be observed at intervals to repose upon the sandstone in the same relations as behind the fort at Fort Point. This fact leads to the conclusion that all of the sandstone in the northeastern part of the city of San Francisco is inferior to the serpentine. For the remainder of the distance to Mission Valley the contact of the serpentine and sandstone is concealed by sand. The rocks which constitute the prominent conical hill in the western part of Calvary Cemetery probably repose upon the serpentine and represent a remnant of the roof which once arched over it. The vertical diameter of the Presidio laccolite can not be satisfactorily determined. It is demonstrably over 300 feet thick, and it may be twice this value. A thickness of 500 feet may safely be assumed. This thickness, it will be observed, is small relatively to the lateral extent, and gives it the form of a very flat lens.

About three-quarters of a mile south of Fort Point the Presidio laccolite and the sandstone upon which it rests are cut off sharply by a fault which is very well revealed in the sea-cliff. The rocks to the south of the fault are evenly bedded sandstones with lignitic shales, dipping toward the fault at an angle of about 45°. A small wedge of red radiolarian cherts has been caught up in the movement, and appears between the sandstone and the serpentine. The downthrow appears from the dip of the rocks to be on the side occupied by the serpentine. The extent of the displacement can not be arrived at precisely. It can scarcely be less than 1,000 feet and may be much more. The strike of the fault plane is northwest and southeast, but it can not be traced far in the latter direction on occount of the blown sand.

The serpentine which occupies the extremity of Fort Point, and upon which the fort stands, does not belong to the Presidio laccolite. It is a separate mass. It underlies the sheet of sandstone upon which that laccolite reposes. It is seen in clean cliff section to present an intrusive contact against the lower side of the sandstone. It is probably the upper portion of a deeper laccolite. In the vicinity of the contacts of the serpentine and sandstone there is some secondary veining, the fissures being occupied by datolite and carbonate.

THE LACCOLITES OF THE POTRERO AND HUNTERS POINT.

On the east side of Mission Valley lies the Potrero serpentine mass. This occupies a triangular area of about 1 square mile. The hill is

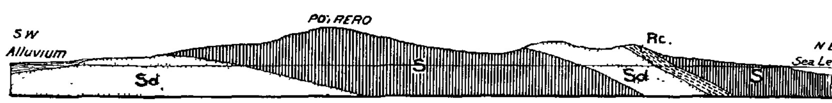


FIG. 7.—Northeast and southwest section through the Potrero laccolite. *Sd* = Sandstone, *S* = Serpentine, *Rc* = Radiolarian chert. Scale, horizontal and vertical: $\frac{1}{5000}$.

composed of two ridges. The main ridge is on the southwest side of the triangle and extends from Islais Creek to Mission Creek. It has a maximum altitude of 326 feet. The subordinate ridge extends from Point San Quentin to Mission Bay and has a maximum altitude of 180 feet. The serpentine of this area is geographically distinct from the Presidio laccolite, and it may be also geologically separated from the latter by the erosion which evolved the intervening valley, having cut through the serpentine down to the sandstone upon which it reposes. It may be discussed as a separate occurrence. The laccolitic character of the serpentine is here again very apparent, and although it is not a simple lens, it may be referred to as the Potrero laccolite. The floor of the laccolite, with the serpentine resting upon it, is well exposed a little to the east and southeast of the city and county hospital on Kansas street, Rhode Island street, and in the gulch between Yolo and Nevada streets. The floor is evidently much warped and buckled, and the sandstones and shales of which it is composed are intensely crushed and sheared. Above this rises the great mass of serpentine which constitutes the main ridge of the Potrero.

The subordinate ridge of the Potrero is largely occupied by a belt of San Francisco sandstone with some associated radiolarian cherts, the latter being confined to a small patch on the northeast side of the ridge. This belt of sandstone clearly reposes upon the serpentine of the main ridge and dips away from it to the northeast. It is thus a portion of the roof of the laccolitic lens. This belt of sandstone is continuously traceable in good outcrops from Jackson Park southeasterly to the old shore-line of Islais Creek marsh, a distance of nearly a mile. Between Jackson Park and Potrero avenue it is interrupted by a small valley, but beyond Potrero avenue it again appears and continues well exposed on either side of Sixteenth street as far as the Southern Pacific Railway track, where the alluvium of Mission Valley is reached. The thickness of the serpentine lens between the floor and the roof is probably about 500 feet. This serpentine mass, thus intrusive between two portions of the San Francisco sandstone, is not, however, all of the serpentine of the Potrero. Reposing upon the upper sandstone and upon its associated cherts is another distinct mass of serpentine, forming the northeastern flanks of the subordinate ridge. This is clearly another and higher intrusive lens. The relations of the sandstone and serpentine are illustrated in the accompanying diagrammatic section (fig. 7).

The Hunters Point serpentine mass is the most southeasterly portion of the belt of this rock which extends across the city. It forms a ridge which is 1¾ miles long, and occupies an area of about seven-ninths of a square mile. It is separated from the Potrero laccolite by the tidal marsh of Islais Creek, which is about three-quarters of a mile wide. The maximum elevation of the ridge is 260 feet. The contact of the serpentine with the rocks of the Franciscan series is observable on the south side of the ridge and at both ends. The contacts are interesting for the reason that the serpentine here comes against three different formations of the Franciscan series, viz, the sandstone, the radiolarian cherts, and the volcanic intrusives. These contacts point again to the intrusive character of the mass; but they indicate further that the Franciscan strata were here disturbed prior to the invasion of the peridotite magma, and that the plane of rupture against which the magma solidified had cut indifferently across the various formations. The laccolitic character of the serpentine of Hunters Point is not less pronounced than that of Fort Point and the Potrero. The lens very clearly rests upon a floor of Franciscan rocks. The superposition of the serpentine upon the sandstone is well revealed at the northwest end of the ridge, and the contact is thence traceable around the south side of the ridge for the greater part of its length. Near the end of the point, between the Chinese fishery and the dry dock, the floor of the laccolite again appears, and the serpentine is seen to rest indifferently upon sandstone (with conglomerate), radiolarian chert, and a spheroidal basalt which is very clearly exposed in the quarry at the end of the ridge in irruptive contact with the chert. On an easterly spur from the highest point of the ridge there is a patch of sandstone and radiolarian chert which rests upon the mass of the serpentine. It would thus appear to correspond to the belt of sandstone and chert which occupies the subordinate ridge of the Potrero, as above described.

The serpentine of both the Potrero and Hunters Point is remarkable for the great number of short sheet-like or lens-like masses of medium-grained, dark, greenish-gray rocks. These rocks have been investigated petrographically by Mr. Palache[1] in his study of the Potrero serpentine. He shows that the rocks belong to the hypersthene diabases, and in their more altered forms to the epidiorites. They have a strongly marked linear distribution both on the Potrero and along the ridge which terminates in Hunters Point. Their discontinuous character is the most remarkable feature of their occurrence. They appear to be inclusions in the serpentine. Their resistance to weathering is greater than that of the serpentine, so that they project quite commonly above the general surface, and in some cases seem to have become detached from the serpentine and to lie on the surface. By far the greater number of them are embedded in the serpentine, and although discontinuous they have a common strike. When they are more critically examined, under favorable conditions, it is usually seen that the edges of these sheets or lenses where they come in contact with the serpentine are very fine-grained to aphanitic, while the texture becomes coarse toward the middle of the sheet, precisely as in the case of a diabase dike. This at once suggests that they are intrusive in the serpentine. Conceding that they are intrusive, it is clear that there is something unique in their small individual extent, their great numbers, and their local occurrence, all being confined so far as is known at present to the serpentine mass.

The fact that very many of these masses of hypersthene diabase or epidiorite which can be satisfactorily examined are approximately horizontal in their attitude, indicates that they are to be regarded as sills rather than as vertical dikes. Their great multiplicity is possibly due, as Mr. Palache has suggested, to the disruption and sundering of a few intrusive sheets in consequence of the movements which have clearly affected the serpentine. It has yet to be explained why they are confined to the serpentine and do not traverse the contiguous formations. Somewhat similar occurrences have been studied by Mr. Ransome in the serpentine of Angel Island.[2] These studies have led Mr. Ransome to the conclusion that the included masses are probably dikes which antedate the serpentine, the latter at the time of its intrusion following the same fissure, breaking up the preexisting dike, and including its fragments in the peridotite magma. In view of these apparently conflicting views the writer reserves any expression of opin-

[1] Lherzolite-Serpentine and Associated Rocks of the Potrero, San Francisco. Bull. Dept. Geol. Univ. Cal., vol. 1, No. 5.

[2] Geology of Angel Island. Bull. Dept. Geol. Univ. Cal., vol. 1, No. 7.

ion upon the question till he has had further opportunity for the study of these occurrences in the field.

For details as to the petrography of these interesting rocks Mr. Palache's paper should be consulted. His analysis of the rock having the epidiorite facies is here quoted:

SiO_2	47.41
Al_2O_3	16.03
Fe_2O_3	2.66
FeO	7.05
MnO	Trace.
CaO	12.33
MgO	5.81
K_2O, Na_2O	4.47
P_2O_5	Trace.
TiO_2	1.29
H_2O	2.19
Total	99.24
Sp. gr	2.96

THE LAS PULGAS LACCOLITE.

Perhaps the most instructive and interesting occurrence of serpentine in our field is that which forms the greater part of the Las Pulgas Ridge. This ridge has a pronounced topographic individuality. It is bounded on the west by the valley now occupied by Crystal Springs Lake, on the north by the deep, incisive canyon of San Mateo Creek, and on the east and south by the wider Almshouse Canyon. The ridge is rather flat-topped, save for the sharp Cone Hill, which rises prominently above the general level on the north side near the middle, and a similar but less prominent elevation just southeast of this. The long slope of the ridge is toward the west, the crest of the ridge being on the east side, where a precipitous bluff overlooks the Almshouse Canyon. The western declivity of the ridge to the level of Crystal Springs Lake is much gentler. From this description and more especially from an inspection of the map it will be apparent that the ridge, thus bounded on all sides by sharp valleys which frequently have very precipitous walls, lends itself admirably to a stereographic determination of its structure. Owing to the clearness of the exposures, the horizontal and vertical elements of the distribution of the different formations down to valley bottoms may be definitely ascertained. The mapping under these favorable conditions shows that the precipitous east side of the ridge, from the bottom of the Almshouse Canyon to the crest of the ridge, is composed chiefly of sandstone, with a very subordinate proportion of volcanic rocks and radiolarian chert. As soon as the top of the cliff is reached a sheet of serpentine appears, resting evidently on the sandstone. On the steep southern wall of San Mateo Canyon, at the north end of the ridge, the superposition of the serpentine upon the Franciscan rocks is even more clearly apparent, for the reason that the contact lies along the face of the cliff. Here the entire lower portion of the stream cliff, and to the west the whole of the cliff, is occupied by volcanic rock of the Franciscan series, while the serpentine rests upon it. The flat top of the ridge and the western slope down to the shore of Crystal Springs Lake is occupied almost entirely by serpentine, with occasional remnants of roof still reposing upon it. It is thus apparent that we have exposed for inspection the eastern edge of an intrusive lens or laccolite of serpentine. That it is essentially the original feather-edge of the lens, and not one developed by truncation due to erosion, is apparent from the fact that it ends against the base of Cone Hill and the similar elevation to the southeast of it. The lens thickens rapidly toward the west and is cut off abruptly at the straight, narrow valley of Crystal Springs Lake, probably by a fault. The intrusive character of the serpentine is proved by the numerous inclusions of sandstone, schist, chert, and volcanic rock (basalt) which are found in it on the western slope of the ridge. The accompanying diagram (Fig. 8) will illustrate better than further detailed description the structure of the laccolite.

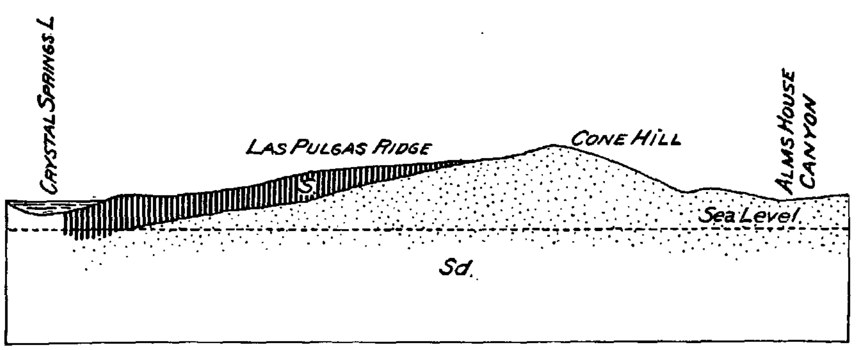


FIG. 8. Section through the Las Pulgas laccolite. *Sd*=Sandstone, *S*=Serpentine. Scale, horizontal and vertical: 3 inches=1 mile.

THE SERPENTINE OF BURI-BURI RIDGE.

Although now forming an isolated mass, the Las Pulgas laccolite is not limited in its extent to the ridge from which it is named. It extends far to the northwest, along Buri-buri Ridge, with essentially the same structure. The latter ridge is disconnected from Las Pulgas Ridge simply by the accident of the transverse canyon of San Mateo Creek. The flat-topped character of the ridge, with steep slopes on either side, is maintained throughout its entire length to San Bruno Creek. For the first 3 miles of the ridge from San Mateo Canyon the greater part of the approximately level plateau-like summit is occupied by serpentine and occasional isolated patches of the Franciscan strata, which appear in the midst of it, or extend into it from the surrounding region in the form of finger-like lobes or belts. As in the case of Las Pulgas Ridge, the occupancy of the summit of the ridge by the serpentine suggests the direct superposition of the latter upon the sandstones and other rocks of the Franciscan series, which form the steep slopes on either side. There seems to be no escape from this interpretation of the general structure. It is borne out by the occasional dikes which cut the Franciscan rocks on the slopes of the ridge, and which sometimes appear to be in direct continuity with the mass occupying the plateau summit. Besides the dikes, there are numerous outlying patches of serpentine in the vicinity of the main mass, which are doubtless remnants of the former extension of the latter.

The map must be consulted in order to properly appreciate the argument from the relative distribution. With the map before us it becomes apparent that the extension of the Las Pulgas laccolite along Buriburi Ridge takes on the form of a much more attenuated lens and becomes in reality a comparatively thin sheet, tapering northward. For not only is the lower limit of the sheet in general easily traceable on the brow of the hill which supports the plateau on both sides, but patches of sandstone and metamorphic schists are found on the summit in such relation to the serpentine that they can be regarded only as resting upon it. They thus represent remnants of the roof of the laccolite. The thickness of the lens, as arrived at by estimating the vertical distance between the floor and roof, where these are not represented in direct vertical section, gives somewhat uncertain results, particularly as mapping demonstrates that the floor is a very uneven surface. In general, it may be said that the lens of serpentine varies from a few feet in thickness toward the north to several hundred feet where exposed on the north wall of San Mateo Canyon. At this place the serpentine evidently occupies a space in the Franciscan rocks which was once a subterranean channel, from which it spread toward the north in the form of a thinner lens between the strata.

Farther north along the ridge toward San Andreas dam and beyond, as well as on the eastern flanks of the ridge, there are several well-defined dikes of serpentine. These range up to three-quarters of a mile in length and are usually from 100 to 300 feet in width. They are nearly vertical in attitude and have a straight trend across hills and ravines. There are also many small patches whose relations are not quite clear. They may be locally intrusive.

The dikes of Fifield Ridge have already been alluded to. The mapping is so demonstrative of their character that further comment is unnecessary.

Enough has been stated to show that the more important masses of serpentine on the San Francisco Peninsula are of irruptive origin, and are the alteration products of peridotite or of allied pyroxenite. It remains for the writer to say that, after a careful examination of the field, he has found not a single occurrence of serpentine to which he would hesitate to ascribe a similar origin. The serpentines of the peninsula are entirely analogous to those which he has met with elsewhere in the Coast Ranges.

THE TEJON (?) SANDSTONE AND MONTEREY SHALE.

These formations do not occur within the limits of the field with which we are immediately concerned. They are found, however, well exposed on the lower portion of Pilarcitos Canyon, immediately south of the southern boundary of the Millbrae atlas sheet. Their consideration would not be introduced here were it not for their importance in the interpretation of the historical geology. A brief note concerning these formations is all that will be attempted, and this simply to emphasize their presence as factors in the general problem. The sandstone is not known to be Tejon, and its reference to that horizon is doubtful. The evidence which warrants such a reference is its position beneath the Miocene (Monterey series) and its resemblance to the Tejon sandstone, which has a curiously cavernous weathering wherever it is known, in various parts of the State. This formation both reposes upon the surface of the granite in its original relation and is faulted against it, the fault being that which is discussed later as limiting the Montara fault block to the southwest. Above the sandstone, which presents an exposure about 500 feet thick, reposes the characteristic white, siliceous shale of the Monterey series. This shale occurs abundantly around the Bay of Monterey, and has been referred to in some detail by the writer in a former paper on the geology of Carmelo Bay.[1] It seems now to the writer, as a result of observations communicated to him by letter by Dr. G. J. Hinde, to be in general richer in siliceous organisms than he was disposed to concede in his former paper. Three specimens of the shale from Pilarcitos Canyon and neighboring sections were sent to Dr. Hinde among others of this formation from different parts of California. Dr. Hinde has kindly examined them with reference to their possible organic remains, and has supplied the following notes. Concerning the first he says: "Thin sections show rounded grains and wavy films of dark material, probably asphaltum. There are a fair number of angular mineral fragments. The only indications of organisms are circular transparent spaces, which may result from diatoms. The rock has the aspect of being of organic derivation, although no organic structure is now preserved." Of the second specimen, from a point north of Pilarcitos Canyon, he notes that it is "a gritty rock, with grains of quartz and particles of mica; streaks or films of asphaltum are present, but no trace of organisms." Of the third specimen he says: "It is a hard, flinty rock; thin sections are dirty, filled with opaque specks; the only organism seen is a radiolarian and some doubtful spicules."

---

[1] Bull. Geol. Dept. Univ. Cal., vol. 1, No. 1.

THE MERCED SERIES.

OCCURRENCE.

Next to the Franciscan series the most important terrane of sedimentary rocks with which we are concerned is the great volume of strata for which the writer has, in a former paper, proposed the name Merced series.[1] The rocks of this series occupy two geographically separate areas within the limits of our field, one on either side of Montara Mountain. The larger and more important portion of the terrane underlies Merced Valley, and thus stretches as a diagonal belt across the peninsula from northwest to southeast in conformity with the general strike of the country. The southwestern edge of the belt is a sharply defined line whose course has already been indicated in describing the limits of the Franciscan terrane, against which the Merced rocks rest. The northeastern edge of the belt is much more obscure. It lies along the base of the San Bruno Range and is concealed by the Terrace formations and the sand dunes. The series is splendidly exposed on the sea-cliffs between the outlet of Lake Merced and Mussel Rock, and very effectively, also, in many of the canyons which gash the southwestern slopes of the valley.

The smaller portion of the terrane occupies the sharp, straight ridge which extends from Pillar Point to a little north of Seal Cove, on the ocean, and separates Halfmoon Bay Valley from the shore. Along the sea-cliffs of this ridge the strata which compose it present all the exposures that could be desired for determining the relation of the strata to the adjoining terrane, the petrography of the series, so far as it is here represented, and the general structure of the ridge.

PETROGRAPHY.

The rocks of the Merced series are chiefly soft sandstones of varying degrees of coherence. In some cases they are quite firm and compact, but for the most part they may be easily broken with the fingers, and many beds are little more than compact sand. There is for a considerable portion of the total volume a large admixture of clayey material, and the rocks would be classed as sandy shales. Beds of pure clay-shale are practically absent, although there are occasional beds of dark, clayey mud in which fossils abound. Hard shell beds firmly cemented, generally with an abundant admixture of gravel, and hard, thin beds of cemented gravel, practically free from shells, occur at intervals. There are also soft or uncemented shell beds, and occasional beds of hard, bluish-gray sandy limestones. Thin lignitic layers are occasionally observed, and volcanic agency has contributed a thin bed of white volcanic ash in the upper portion of the series.

[1] Bull. Dept. Geol. Univ. Cal., vol. 1. No. 4.

FOSSILS.

The recorded fossils of the Merced series on the north side of Montara Mountain have been listed by the writer in the paper above referred to, and it is not deemed necessary to reproduce the list here. The following additional fossils have since been found in the paleontological collection of the University of California, and may be added to the list already given:

Cardium Corbis, Martyn, sea-cliff south of Lake Merced
Cardium Meekianum, Gabb, Twelve Mile House.
Trochita filosa, Gabb, Twelve Mile Creek.
Machæra patula, Gabb, Twelve Mile Creek.
Cryptomya Californica, Con., Twelve Mile Creek.
Calista Voyi, Gabb, Twelve Mile Creek.

In the portion of the terrane which forms the Pillar Point Ridge, on the southwest of Montara, the following fossils have been collected by the writer, who is indebted to Dr. Dall for their identification:

Chrysodomus or *Purpura crispata.*	*Mactra albaria.*
Mactra (*Standella*) *Californica.*	*Mactra planulata.*
Balanus.	*Pecten catilliformus.*
Astyris.	*Siliqua* (sp. indet.).
Purpura (like *saxicola*).	*Macoma.*
Natica (sp. indet.).	*Lucina acutilineata.*
Mactra (sp. indet.).	*Lucina multilineata.*

STRATIGRAPHY AND STRUCTURE.

The most remarkable features of the Merced series are (1) the great volume of its strata and (2) the deformation to which it has been subjected at so recent a period in geological history. The general facts as to the volume of the series have been stated in the original note on the Merced series, and in this sketch it will not be necessary to do more than repeat the statement of results there given in order to have clearly before us an important factor in the discussion of the post-Pliocene orogeny of our field. The earlier statement of the structure of the series, and of its tectonic relations, will here be supplemented in an important particular.

The strata of the Merced series, which form the southwestern side of Merced Valley, dip toward the axis of the valley to the northeast. This dip, as revealed in the cliff section between Lake Merced and Mussel Rock, is persistent across the entire breadth of the valley. At Mussel Rock the base of the series is exposed resting in direct contact upon a worn surface of Franciscan rocks. The basal bed is a forest soil in which cones of *Pinus insignis* (Monterey pine) abound. It undoubtedly represents the land surface just prior to the depression which initiated the accumulation of the Merced series. The surface upon which this coniferous material rests is tilted to the northeast conformably with the dip of the overlying strata. From this base the strata are magnificently exposed in ascending series to near the outlet of Lake Merced, a distance along the beach of 20,000 feet, or over 3¾ miles. The dip and strike are easily observable along the entire distance, and it is a simple problem to calculate the thickness of the series within moderate limits of error. The thickness thus measured is about 5,800 feet, a value which makes the series the most voluminous body of Pliocene rocks in North America so far as our records at present show.

From the attitude of the strata it is apparent that Merced Valley is a structural depression or local sag in the crust. In the original note on the Merced series the depression was referred to as a syncline. This reference is only a partial expression of the truth. In that note the writer refrained from discussing the tectonic relations of the northeastern edge of the Merced terrane. The reason for this was that these relations then appeared problematic, and his diagrammatic section of the series along the coast was accordingly cut short at the outlet of Lake Merced, where observational evidence ended. It was hoped that further familiarity with the field would yield some direct evidence of the structure. Additional study has shown that it is futile to hope for direct evidence of the relation of the northeastern edge of the Merced series to the older rocks except from the records of borings. The line of contact of the Merced and Franciscan terranes on this side of the valley is hopelessly buried by the Terrace formations or by æolian sand.

While thus recognizing the lack of direct and positive evidence on this point, a further consideration of the limitations of the problem has brought out more clearly the force of the inferential evidence, and it is now realized that there is only one possible relation between the northeastern edge of the Merced terrane and the Franciscan terrane. This relation is that of a great fault, whereby the newer rocks underlying the valley in such great volume have been let down against the older terrane.

The argument is briefly as follows: The Merced series is about a mile thick; it rests unconformably upon Franciscan rocks; from its southwestern outcrop it dips uniformly to the northeast to a line parallel with this outcrop at the base of the bold scarp-like front of the San Bruno Range; this range is composed of the same Franciscan rocks as the basement of the series. Under these conditions no other relation is possible for the abutment of the Merced strata against the base of the San Bruno Range than that of a fault. In detail the course of the fault can not be traced, since the Terrace formations and the sand dunes obscure it; but its reality can not be denied credence and its general trend may be approximately defined. It undoubtedly lies close to the base of the San Bruno Range and parallel to it. From this conclusion it becomes apparent that the first discussion of the diastrophism of the Merced series was timid and halting. The orogenic movements which have affected the region are found to have been even more violent than were then supposed. To the Montara upthrust there is now added the upthrust of the San Bruno fault block. The portion of the peninsula between the base of the San Bruno Range and the crest of Montara thus partakes of the general character of a tilted block. It is not, however, a simple case of tilted fault block, as it is traversed by faults and shear zones.

The Merced Valley is thus analogous in its general structure and origin to the fault valleys of southern Oregon, so well described by Russell, and the synclinal sag which is apparent in the dip of the rocks is a subordinate feature. The failure to recognize the San Bruno Range as an uptilted fault block interfered with a full appreciation of the nature of the local unconformity between the Merced series and the terrace formations of the Pleistocene. The extent of the unconformity is also masked by the fact that the upper beds of the Merced series flatten out in their dip where they pass beneath the terrace formations. Further study of the field shows that the formations of the Merced series are nowhere observable to the northeast of San Bruno fault, and that the terrace formations to the northeast of the fault line rest directly on the Franciscan terrane, and to the southwest of the fault upon the Merced terrane. That is, they have been spread out over the trace of the fault after the formations of the Merced series had been removed from the surface of the uplifted San Bruno Range. There is thus an important interval between the faulting of the Merced series and the deposition of the terrace formations.

At the northern end of the narrow ridge, extending from Pillar Point to beyond Seal Cove, the sections reveal the local base of the series in the form of a bowlder beach reposing upon a granite surface. The bowlders are chiefly granitic, and the interstitial spaces are filled with beach sand now more or less firmly cemented. The bowlders vary in size from a few inches to several feet in diameter. They are generally subangular, and are evidently derived from the underlying granite. They are very commonly coated with a layer of balani in a good state of preservation, and frequently bowlders of sandstone show the ancient borings of mollusks, now filled with compacted and cemented sand. This ancient Pliocene beach reposes in part upon a wave-cut terrace carved out of the granite. This terrace has an altitude above the present high-water mark of about 8 feet. Reposing upon the compacted conglomerate of the beach is a dark, sandy, clay-shale, rich in fossils. Above this are several hundred feet of shales, shaly sandstones, and some hard sandstone beds. These strata are exposed in various attitudes along the sea-cliff to Pillar Point, and on the wave-cut terrace they may be seen at low water along the shore. The rocks have been thrown into various positions, and the structure varies rapidly across the general strike. Along the main ridge the rocks are in general inclined at very high angles, and are in places quite vertical. A few hundred yards out to the west of the axis of this ridge of highly inclined strata the same beds are seen at low tide, on the wave-cut terrace which fringes the cliffs, to be thrown into low anticlines with their complementary synclines. The crests of these anticlines have been truncated by wave action, and the strata have beautifully defined circular or oval strikes, the hard beds jutting above the general level of the terrace. These structural circles or ovals are only a few hundred yards in diameter, and there are many of them in sight at low tide. There are smaller ones, less than 100 feet in diameter, where the anticlinal dome or synclinal saucer structure is as sharply defined as if it had been modeled. Some of these may be critically examined, as they are close to the base of the cliffs and are sufficiently bared at low water for complete inspection. The most of them, however, are too far out, and although their structure is perfectly apparent, they can not be reached. A similar low, anticlinal arch may be seen in the face of the cliff which forms the southern aspect of Pillar Point. This, also, is just to the west of the main axis of the ridge, where the strata are more highly inclined and occasionally vertical. Across the face of this cliff, from the east side to the west, a distance of several hundred yards, extends a low arch in the strata, which is accentuated by a hard bed of sandstone that weathers out prominently at the top of the cliff, and gives precision to the arch, the bedding in the lower shaly rocks being less clear. On the west limb of the arch this hard bed has broken under the strain of the folding, and a small overthrust fault several yards in extent has been formed.

From the general structure of this belt of rocks it is difficult to resist the conviction that they have been crowded up against the granite basement by lateral thrust from the direction of the ocean. The presence of the base of the formation a little above sea-level indicates, as in the case of the base at Mussel Rock, a depression since the inauguration of sedimentation whose minimum measure is the thickness of the series. Since the depression it has been reelevated above sea-level. This ancient beach has therefore experienced the same vertical movements as the base of the Merced series at Mussel Rock, and may in a general way be correlated with it. Specific correlation in the sense that the beach was formed at the time when the coniferous bed at Mussel Rock was being submerged can not be safely made, since the beach may be only one of a long series formed by the transgression of the sea upon the land during the Pliocene subsidence.

THE TERRACE FORMATIONS.

The latest of the marine deposits which occur on the San Francisco Peninsula are spread over the slopes of the land at various altitudes from about 750 feet down to sea-level. In certain localities they constitute well-defined terraces, and, in general, they are believed to be deposits which accumulated offshore at various stages of the latest emergence of the peninsula from beneath the waters of the Pacific.

They are therefore, for convenience, termed the "Terrace formations," and they are correlated with the deposits similarly designated at Carmelo Bay.[1] The Terrace formations are composed of light-yellow sands, which, although generally well stratified, have not been consolidated. The material is probably of local derivation and represents the products of the disintegration of the Merced series. On the north side of Merced Valley these sands rest upon the eroded surface of the Franciscan terrane, and are in turn partially mantled by the sand dunes which have been developed from them and from the sand blown in from the ocean beach. The Terrace formations flank the lower slopes of the hills of San Francisco, passing in between the latter up to a maximum elevation of about 750 feet, but as a rule reaching a much less altitude. The higher remnants of these formations are found only in the sheltered embayments of the hills, or on terraces which are not in the course of the drainage of upper catchment slopes. Elsewhere the processes of denudation have carried the sands down to lower levels. The highest area of these sands is on a terrace on the northeast side of San Bruno Mountain at about 750 feet. On the southwest slopes of the same ridge the formations reach in places an altitude of from 660 to 680 feet. In the ravine west of Las Papas Ridge they attain an altitude of about 650 feet, but for the greater part of their distribution around the flanks of the hills they have been swept away down to elevations of between 400 and 500 feet. At these and lower elevations the terraced effect of the gently sloping sands at their abutment upon the steep hillsides is in some localities pronounced.

It is very apparent from the relation of these Terrace formations to the hills that the latter had practically their present topography prior to the deposition upon their flanks of the newer rocks. The modification of that topography by wave-cut terraces at the various stages of the uplift, and by subaerial erosion since the uplift, has not to any important extent changed the character of the hills. On the southwest side of Merced Valley the Terrace formations are spread out over the surface of the Merced terrane, and are difficult of discrimination from the latter. Even in the fine sea-cliff section south of the outlet of Merced Lake the two sets of strata present no notable unconformity, owing to the fact that the upper beds of the Merced series have a very low angle of dip at the north end of the section, where the Terrace formations rest upon them. At a point about 1 mile south of the outlet of the lake upon the shore there is evidence of erosion of the upper beds of the Merced series, as if the latter had been brought within the action of scouring currents. Above this there are some dark-brown, somewhat peaty, beds, which are probably diatomaceous. This horizon is supposed to mark the base of the series of sands here referred to as the Terrace formations. Above this horizon they have a thickness of between 100 and 200 feet. A satisfactory statement as to

[1] Geology of Carmelo Bay. Bull. Dept. Geol. Univ. Cal., vol. 1, No. 1.

the thickness of this formation in general is difficult to formulate. Although they reach up to an elevation of 750 feet, nothing can really be inferred from this fact as to the thickness of the deposit; for at the various higher Terrace stages the sands formed probably only a narrow littoral belt, thick near the shore and sloping down the submerged hillsides into deep water, but not filling up the depressions between the hills. At the lower Terrace stages there is good evidence that the depression between the hills and Merced Valley itself were filled up nearly to the shore-lines, so as to render the water shallow. This embankment probably attained its maximum development at a stage of the uplift when the land was about 300 feet lower than at present. This would give a thickness for the Terrace formations occupying Merced Valley of at least 300 feet. The effect of the uplift subsequent to this stage has been to degrade the embankment.

THE DIASTROPHIC RECORD.

The diastrophic events which have left their stamp upon the geology of the San Francisco Peninsula challenge attention by the incisiveness and boldness of their character. From the earliest condition of which we have any record revolution has followed so closely upon the heels of revolution, and each has effected such radical changes in the preceding set of conditions, that it becomes clear that the term "event" can only be used by reason of its convenience, and that what we call events are but the culminating phases in a wave of diastrophic action which seems never to have ceased. We have no record of periods of quiescence. Uplift and depression have seemingly been geologically continuous, yet not as a simple rhythm. So far as our limited knowledge warrants a judgment, the process of events has been chaotic rather than rhythmical. Violent rupture and dislocation of the crust, throwing it into faulted, discordant blocks, have been features of the agitation. Volcanism has been intimately interwoven with disastrophism in relations which we can do no better than guess at. The crust has in succession been invaded by batholitic granite magma, has exuded enormous quantities of basaltic magma and been again invaded by laccolitic peridotite magma. The geology of the region can not be better summarized than by giving a brief statement of the sequence of these grand events so far as we can make them out.

The first rocks that we know are those which formed the crust anterior to the invasion of the Montara granite. Of this crust we have but little knowledge, and we must draw conclusions from observations beyond our field for that. That it was composed very largely of limestones and rocks which by metamorphism have yielded quartzites and schists is certain. The age of these limestones is unknown. This crust, rich in limestones, was invaded from below by a granitic magma, and the limestone which was left in contact with the granite assumed the character of marble. This granite was an extensive body of molten rock, and must have displaced an enormous volume of preexisting rock in the crust, either by upheaval or by absorbtion. From its outcrop in Montara Mountain and in similar extensive exposures farther south it is entirely probable that it forms the heart of the Santa Cruz Range of mountains. This granite invasion was accompanied by an uplift which brought the invaded strata within the zone of effective erosion. The proof of this is that the granite was very thorougly stripped of its overlying mantle of rocks before the deposition of the next succeeding series of sedimentary rocks. This denudation effected, the region was submerged and the accumulation of the Franciscan series was initiated. From the nature of this series it is evident that such a great volume of strata could have been piled up only during a progressive subsidence of the coast. At different more or less prolonged periods during the accumulation of the series, the bottom of the ocean sank sufficiently rapidly to be out of reach of littoral sediments. The proof of this is found in the nearly pure foraminiferal limestones, and in the horizons of radiolarian chert. Whether by an outward extension of the shore by delta accumulation, or by a temporary reversal of the downward movement, as if the latter had been abnormally rapid and necessitated compensation by temporary uplift, these sheets of nondetrital rocks became invariably buried by sediments, and the general depression proceeded. The minimum measure of the total depression is the thickness of the Franciscan series.

During this depression there were at various times voluminous outpourings of basaltic lava, with corresponding intrusions in the lower rocks, giving rise to the various sheets of volcanic material found intercalated with the sedimentary rocks of the series. The volcanic products were more voluminous in the middle stages of sedimentation, i. e., of depression, than in the earlier and later.

After the accumulation of the Franciscan series and the cessation of the depression which conditioned it, two events occurred, the relative sequence of which is not known. One of them was the invasion of the upper portion of the Franciscan series by peridotite magma, which solidified in the form of dikes and laccolitic lenses. The other was the uplift of the Franciscan series and the inauguration of its degradation. Whether the peridotite invasion took place before or after the uplift there is no good evidence to show. It seems probable, however, that the peridotite invasion was subsequent to the uplift, and occurred after the Franciscan series had been subjected to a moderate amount of disturbance.

The uplift and consequent degradation of the Franciscan series had proceeded so far that in the Tertiary the Montara granite, which had undoubtedly been deeply buried by the Franciscan rocks, was reexposed and depressed to form the floor for the deposition of the Tertiary sediments. The light-colored sandstone with cavernous weathering, which reposes on the southwest slope of Montara in the lower stretches of Pilarcitos Canyon, is probably the Tejon sandstone. The white shales which overlie it are certainly those of the Monterey series (Miocene), so well developed farther south in the Santa Cruz Range. The Tejon rocks rest directly upon the granite, and, although in general faulted against it, were clearly deposited upon its surface. The Tejon rocks may have been simply a littoral embankment, and the original local distribution is difficult now to determine. It is probable, however, from the wide distribution of these rocks and their remarkably uniform petrographical character throughout the Coast Ranges, that the exposure on Pilarcitos Canyon is but the remnant of a once extensive sheet of sediment which covered the whole of the present region of Montara Mountain. There is, however, room for doubt as to the validity of the assumption. Admitting this doubt, the Monterey shales which overlie the sandstone may, from their petrographic character, be safely assumed to have extended over the whole of the peninsula. They are white, siliceous shales, and must necessarily have accumulated in water sufficiently deep to have been beyond the range of shore sediments. This, coupled with the fact that the relief was probably not so pronounced as it is at present, leaves little room for doubt that these shales are only the remnant of a sheet which was once spread continuously over the region of the present Montara Mountain. This being granted, it follows that the region under discussion again suffered uplift and thorough denudation during the post-Miocene disturbance which so profoundly affected the Coast Ranges generally. This is proved by the removal of the Monterey shale over the greater part of the peninsula prior to the Pliocene depression.

The Pliocene rocks of Pillar Point rest directly upon the Montara granite without the intervention of the Monterey shale or of other strata. This fact is demonstrative of a post-Monterey erosion antecedent to the Pliocene. The direct superposition of the Merced strata upon the Franciscan terrane without the intervention of the Monterey shale is evidence having the same significance. The Pliocene depression is locally measured by the thickness of the Merced series. These strata, it has been shown, have a vertical thickness of over 1 mile. The floor upon which they rest was a land surface immediately prior to the depression. The depression of the region, therefore, must have been such as to sink this floor over 1 mile below sea-level. This depression seems to have proceeded quietly. Toward its close a stratum of volcanic ashes was formed over the area of sedimentation, and became a constituent member of the series.

After the accumulation of the Merced series orogenic movements were inaugurated which were the chief factors in the development of the present structure and geomorphy of the peninsula. The first of these was the formation of the San Bruno fault and the upthrust of the San Bruno Range, together with the block of mountainous country to the northeast of it occupied by the city of San Francisco. This end of the peninsula has, in a general way, the characters of a tilted orographic block, with many complexities in detail, arising from subordinate faults and flexures of the strata, most of which doubtless antedate the general tilt. By this uplift the region to the northeast of the San Bruno scarp was entirely denuded of the Merced beds which mantled it, and was otherwise subjected to a sculpture which the region on the downthrow of the fault escaped. The differential throw of the fault must have been not less than 7,000 feet. This upthrow of San Bruno and its denudation of the Merced beds were followed by the Montara upthrust, whereby the entire block of country from the base of the San Bruno scarp to Halfmoon Bay received a similar tilt, the axis of uplift being parallel to the first, i. e., northwest and southeast. The great fault scarp of this block is on the southwest side of Montara Mountain, overlooking Halfmoon Bay. The fault has not yet been studied in detail. The tilting of this block was not a simple process but was accompanied by the development of subordinate structural features traversing the block. The most notable of these is the deformation of the Merced series and its sinking in a synclinal sag, evidently by a shearing or faulting along the line of its present contact with the Franciscan terrane, i. e., along a line coincident with the San Andreas fault. At the close of these orogenic movements the altitude of the land was much lower relatively to the sea-level than at present. A general depression of the land seems to have been concomitant with the more acute local disturbances or to have immediately followed them, for we find marine terrace formations strewn over the region at elevations of over 700 feet, with a corresponding baselevel plateau, and remnants of a still older plateau, also the result of baseleveling, at about 1,100 to 1,200 feet above sea-level. The recovery from this depression by stages, and the consequent development of terraces and baseleveled plateaus, together with the accumulation of the Terrace sands and the evolution of a new topography out of the emergent mountain mass, were followed in very recent times by a depression which allowed the sea to invade the Golden Gate and to drown the lower stretches of the streams of the peninsula.

The orogenic movements which effected the deformation and faulting of the Franciscan series are not here considered, since their place in the sequence is not known. By enlarging the field, this and other gaps in the record, which doubtless exist, will, it is hoped, be filled in the future.

GEOMORPHY.

The discussion of the geomorphy of the San Francisco Peninsula is possible only after the salient features of the geology have been comprehended. With the preceding sketch of the geological history before us, we may examine the geomorphy of our field and hopefully inquire into the processes which have been immediately concerned in its development. The excellent maps which are now available enable us to waive detailed description, and we may safely trust to the reader to acquire from them an adequate conception of the aspect of the country. The inquiry as to the development of the features which are so well expressed in the atlas sheets involves the consideration of the following prime geological factors:

(1) The formation, one after the other, of two similarly tilted fault blocks sloping to the northeast and precipitous to the southwest.

(2) The presence of subordinate faults and folds in these fault blocks.

(3) The variously resistant character of the formations constituting these blocks.

(4) The existence of the earlier or more northern block above baselevel and the consequent inauguration of its sculpture before the second block was thrown up; followed by—

(5) Subsidence of the region and formation of the second fault block.

(6) The emergence in unison of these two great block forms from the Pacific.

(7) Their sculpture as conditioned (*a*) by their relation to baselevel at various stages of the uplift; (*b*) by their petrographic heterogeneity, and (*c*) by their structural complexity.

(8) The development, as an episode of the uplift, of marine deposits (terrace formations) on the lower slopes of the fault blocks, constituting upon their emergence secondary constructional or block forms.

(9) The sculpture of the latter.

(10) The development of incidental æolian forms pari passu with this sculpture.

(11) A recent subsidence.

(12) The present relation of the land to baselevel and its effect upon the development of embryonic constructional or block forms, such as tidal flats, deltas, etc.

(13) Aggressive littoral action on the present strand.

TWO DOMINANT FAULT BLOCKS.

The outlines of the two grand constructional or block forms still remain, although their surfaces are deeply scored by erosive agencies. Those of the Montara block are particularly distinct. The sculpture has not yet effaced the characteristic shape of the tilted block. Those of the older, or San Bruno block, are more obscure, and the sculpture has effectively obliterated the original surface of the sloping back of the block, although a portion of the precipitous fault scarp still remains. The topographic features of the San Bruno block may be first considered. These features will be found to belong to two distinct cycles of erosion. Those referable to each cycle will be briefly indicated in turn.

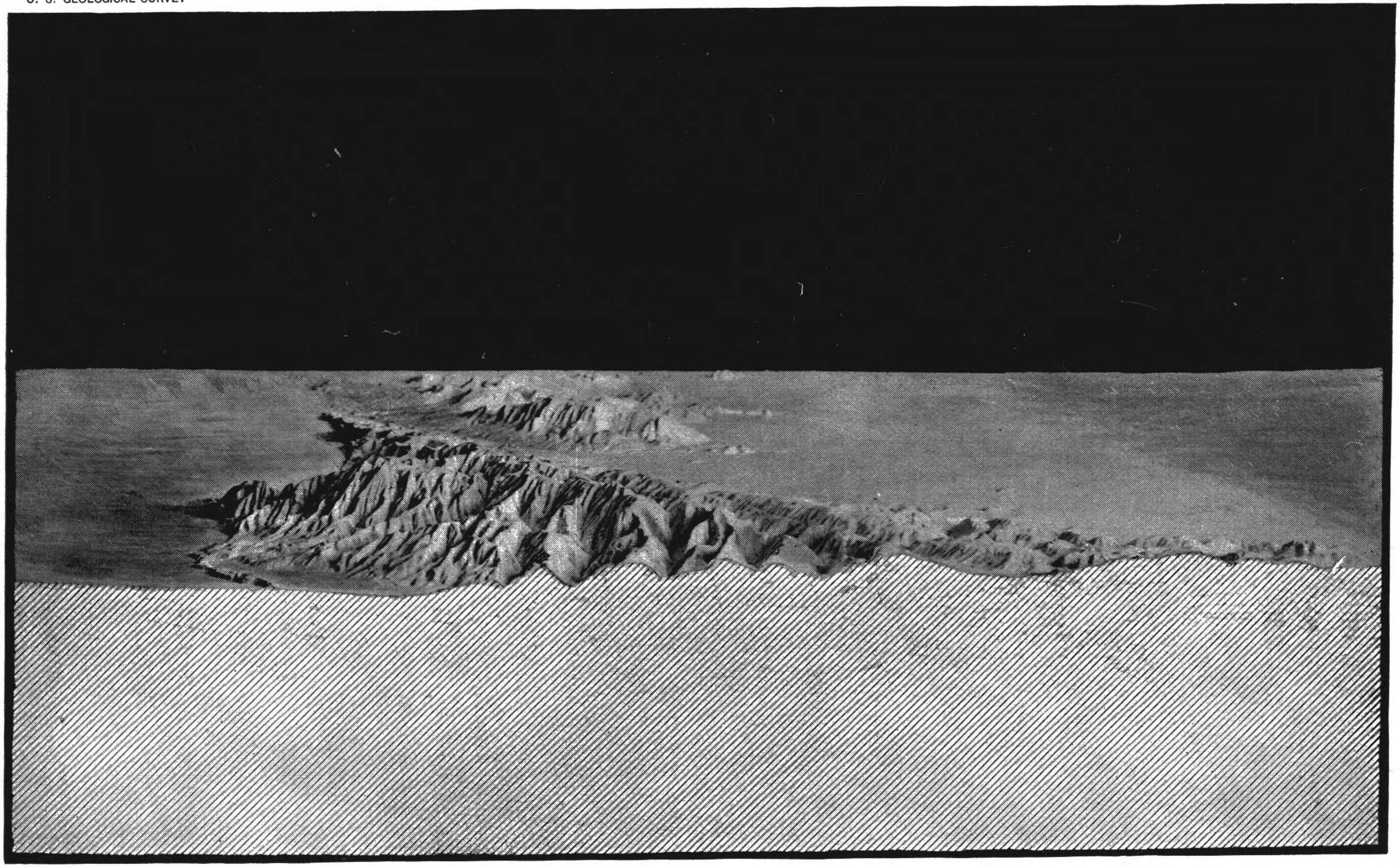
THE SAN BRUNO BLOCK.

The greater age of the San Bruno block as compared with the Montara block is established, as has been previously shown, by the entire denudation of the Merced series from its surface. The greater advancement of the topography toward the condition of maturity testifies to the same fact. This more advanced condition of the topography is apparent in the absence of table-land effects, and in the reduction of the mountain block to numerous isolated ridges, hills, and groups of hills, with wide, open valleys between them. These are the results of a cycle of erosion in which the Montara block has not participated. At the time of the common emergence of the two blocks the San Bruno block had already, as a result of the earlier cycle of erosion, gotten into a condition in which further sculpture proceeds slowly. The Montara block, on the other hand, was virgin, and in the most susceptible condition for rapid and incisive sculpture.

The ruggedness in detail of the hilly country which now represents the San Bruno fault block is largely due to its petrographic heterogeneity, and, in a less degree, to complexity of structure. The radiolarian cherts are responsible for the rugged cluster of peaks which occupy the center of the city of San Francisco. These rocks do not decay, but break down by mechanical disintegration. The sandstones with which they are associated, on the other hand, decay readily as a rule and yield an abundant soil, which is removed to lower levels, leaving the cherts projecting. The serpentine gives rise to a low range of hills extending from Fort Point to Hunters Point. Of these the Potrero and Hunters Point are the only prominent ones, the others being largely buried by the Terrace formations and by sand dunes. The boldest and most massive ridge is San Bruno Mountain itself, which is homogeneously composed of San Francisco sandstone from top to bottom. The bold precipitous front of this mountain, overlooking Merced Valley, is one of the most notable topographic features in our field, and is a fine instance of a somewhat degraded fault scarp. The buttress-like shoulders which support it on the southwest side are due very probably to a fault wedge which has dropped down during the uplift of the main block. These shoulders are in part composed of radiolarian chert and serpentine, which are found generally in portions of the series geologically higher than the summit of San Bruno. The low ridge which terminates on the Bay of San Francisco at Point San Bruno is doubtless structurally referable to this dropped wedge. Other faults occur, but they do not call for special discussion.

Except on the east side of the peninsula, where the sands of the Terrace formations have been cleaned out of the old valleys, the topography ascribable to the earlier cycle is revealed only above an altitude which, on an average, may be placed at between 300 and 400 feet.

The activity of the later cycle of topographic development is manifest in the modifications of this older topography and, more particularly, in the sculpture of the new Terrace formations lying on the slopes of the hills below the general altitude indicated. The sculpture of these block forms has proceeded under two distinct sets of conditions: (1) where the constructional action of the wind has been impotent to hinder the



VIEW OF MODEL OF SAN FRANCISCO PENINSULA, SHOWING THE TWO DOMINANT FAULT BLOCKS AS SEEN FROM THE SOUTH.

degrading action, and (2) where the wind has been powerful and aggressively resistant of degradation. In the former case ordinary stream canyons and ravines have been the result. In the second case the wind has successfully prevented the development of such features, first by contributing to the area in dispute between the conflicting forces more material than the streams remove, and secondly by establishing a surface upon which rain water can not accumulate. The northeastern end of the peninsula is under the constructional control of the wind, and stream erosion is at a minimum. The sand is derived in part from the underlying Terrace formations, but chiefly from the shore drift arising from the waste of the sea-cliffs between Lake Merced and Mussel Rock.

The modifications which have been effected in the old topography of the upper slopes during the later cycle of erosion are not important. These modifications are of two kinds. The first are those due to atmospheric and stream agencies. These are difficult to discriminate, since they are due to the resumption of the same processes as were in operation during the first cycle. These modifications have probably not been important, for the reason above mentioned, viz., that during the earlier cycle the topography had become advanced to a stage where such erosion proceeds somewhat slowly.

The second kind of modification of the old topography is that due to destructive and constructive shore action at the various stages of the uplift. It seems probable that the crest of San Bruno Mountain was determined by the same causes to which are ascribable the 1,200-foot baselevel plateau cut in the sides of the higher Montara block. The summit of the ridge falls into line with the plateau. The terrace at about 750 feet on the north side of the mountain is doubtless due to wave action at the same general stage of the uplift as that at which the 700-foot terrace on the flanks of the Montara block was cut. Other terraces at lower levels are evident features of the topography, but they have added little to its general character, and as we reach the lower slopes the newer constructional effects dominate and it is difficult to say what part wave-cutting action has played. It seems probable, however, from the sand embankments, that the water was shallow and that sea-cliffs were local.

THE MONTARA BLOCK.

When we turn to the Montara fault block we have only one cycle of erosion to deal with, viz, that of the last uplift, and its results are broad and simple. The essential features of the topography are the following: A block of country slopes from the crest of Montara, altitude nearly 2,000 feet, to the axis of Merced Valley, at an angle of about 5°, presenting a bold, precipitous front to the southwest. Both the precipitous front and the gently sloping back of the block have been incisively sculptured. Cut into the sloping back are two great steps or plateaus, one at from 1,100 to 1,200 feet and the other at about

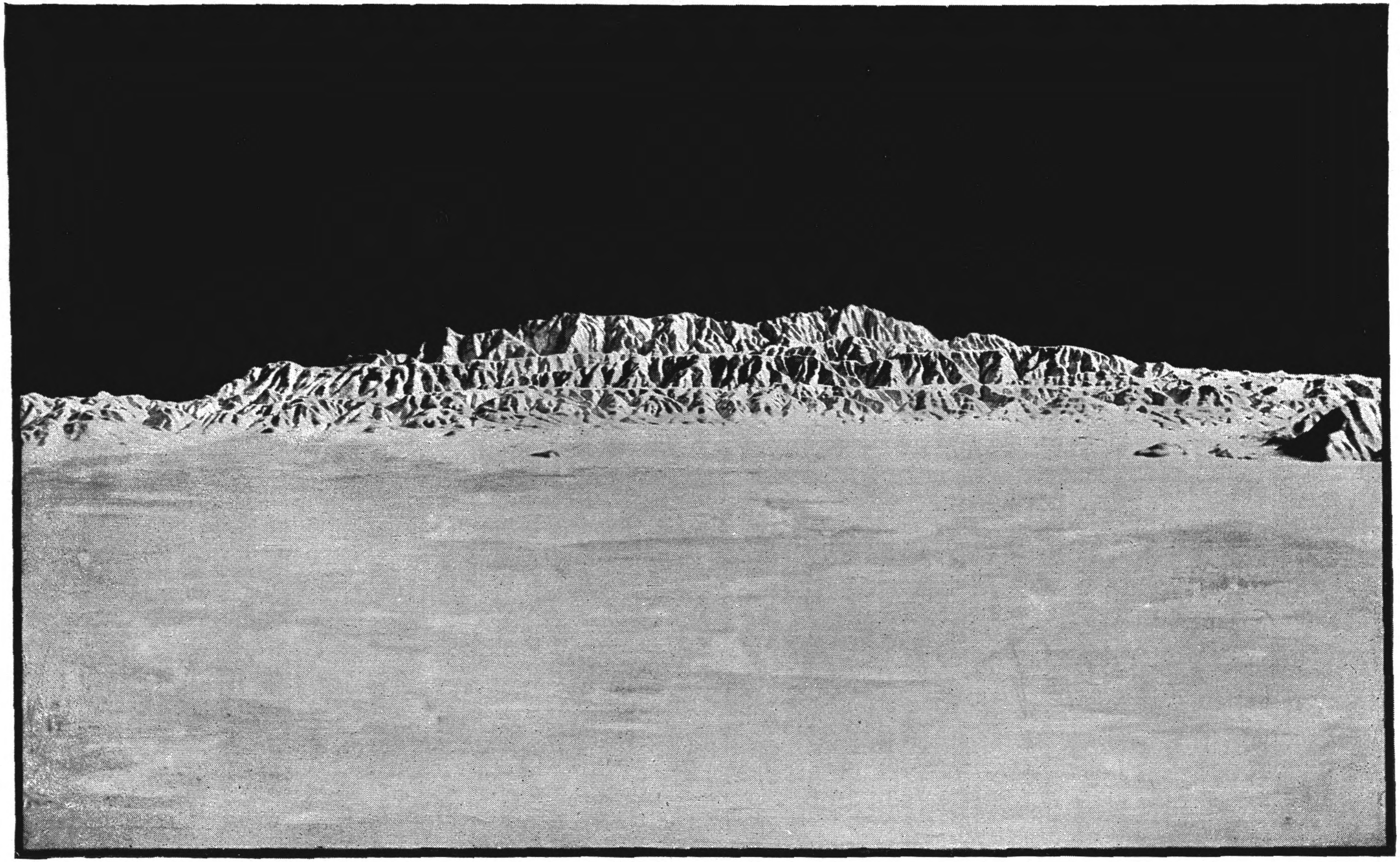
700 feet above sea-level. These plateaus have been dissected by streams and are represented now by flat-topped ridges. The higher of these two great steps may be conveniently designated the Sawyer plateau, from Sawyer Ridge. The ridges of which it is composed are Cahill Ridge, Spring Valley Ridge, Fifield Ridge (in part), Sawyer Ridge, Sweeney Ridge, and some unnamed shoulders of Montara Ridge. The lower is represented chiefly by Buri-buri Ridge and its southeastern extensions in Las Pulgas and other ridges, and may be called the Buri-buri plateau.

Geological investigation shows that these plateaus are the remnants of baseleveled plans, the edges of the strata having been truncated at their surface. These plateau ridges are parallel with the axis of uplift of the fault block, and they are not, except in one very notable instance, traversed by transverse or consequent streams. This instance is that of San Mateo Canyon from Crystal Springs eastward, which cuts completely through the 700-foot plateau ridge at right angles to its trend. The ridges of the 1,200-foot plateau are not so traversed.

The drainage of this slope of the block which was deflected to the ocean has developed large cirque-like canyons, which are eating back into the mountain mass, also parallel to the strike of its structural planes and so shortening the extension of the ridges to the northwest The vigorous erosion which these cirque-like canyons exhibit, as compared with the canyons on the bay side of the divide, is due chiefly to their steeper grades.

On the precipitous or southwest front of the fault block the 1,200-foot terrace is also recognizable in the form of a single flat shoulder or buttress, evidently the remnant of a dissected wave-cut terrace in the front of the mountain. The 700-foot terrace is not clearly distinguishable, but there are terrace-like shoulders strewn with shore drift at altitudes of from 400 to 500 feet. The obscurity of the terraces on this side of the mountain finds its explanation in the more vigorous erosion due to the steeper grades and to the more or less decomposed character of the granite of which this face of the block is composed.

The historical explanation of the sculpture of this fault block appears to be simple. As the land emerged from the ocean it was covered by the little coherent sediments of the Merced series. These were successively removed at lower and lower levels, laying bare the basement upon which they were deposited. At a stage of the uplift when the land was about 1,200 feet lower than at present there was a halt, and baseleveling processes evolved the broad Sawyer plateau. The uplift was then renewed and the next important halt was at a stage corresponding to about 700 feet lower than at present, when the Buri-buri plateau was similarly evolved. Gravels are still found strewn in patches over the surface of the plateau. At this period of horizontal planation the upturned edges of the Merced series were cut off shortly at the baselevel, and none of the formations of this series were left remaining



VIEW OF MODEL OF SAN FRANCISCO PENINSULA, SHOWING THE TERRACED EFFECT DUE TO THE SAWYER AND BURI-BURI PLATEAUS.

Vertical scale of model twice the horizontal.

upon the subaerial slopes save possibly a few lodged pebbles. The uplift was again renewed, and there are evidences of other halts in the process at lower levels, but none so long continuous or so pronounced in their terrace effects as the two which have just been mentioned. The time consumed in the elevation of the Buri-buri baselevel plateau to its present altitude seems to have been relatively short. The soft rocks of the Merced series have not been much degraded by stream action, although an afternoon's ride over the terrane will convince the observer that the agencies working to this end are surprisingly vigorous in their action.

DRAINAGE.

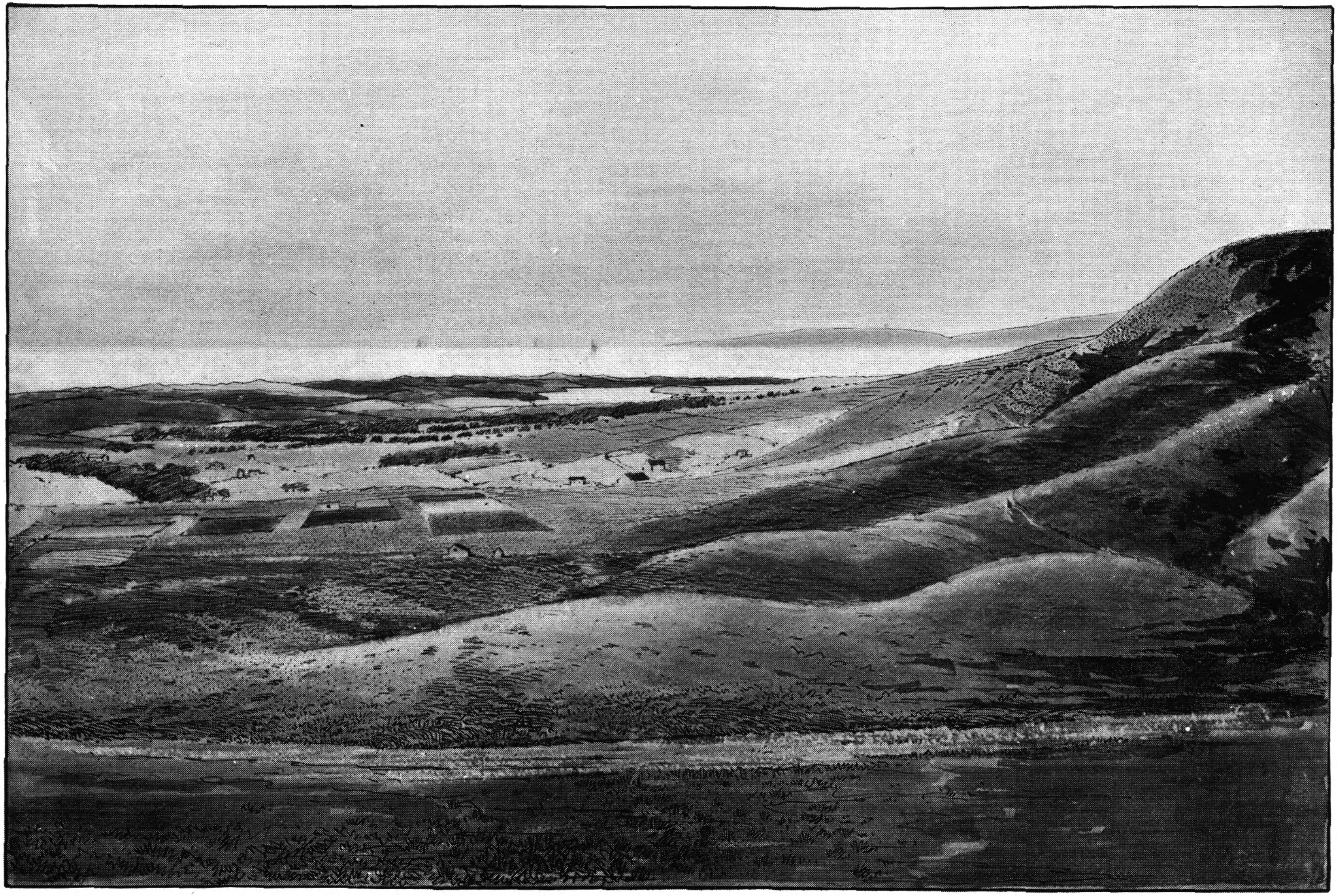
With the inception of the uplift, drainage was inaugurated upon the sloping back of the Montara block. The consequent streams of the original surface, as they sank through the softer Merced formations, become superimposed streams when they reached the surface of the older and harder terranes. Here their history becomes somewhat complex. The longitudinally faulted condition of the block was eminently favorable to the development of subsequent streams. As the latter extended the superimposed consequent streams rapidly atrophied, and only one, the lower part of San Mateo Creek, has persisted, gathering in all the drainage of the subsequent streams of Crystal Springs, San Andreas, and the upper portion of San Mateo. That the lower part of San Mateo Creek is a superimposed stream is evident from its course through the broadest and perhaps the most difficult part of the Buri-buri plateau. The remarkably straight valley of Crystal Springs and San Andreas is a magnificent example of a subsequent drainage system extending laterally along a fault in opposite directions normal to the original consequent drainage. San Mateo Creek above Crystal Springs is also a subsequent stream along a fault. The same is true of Pilarcitos Creek, which now drains directly to the ocean at Halfmoon Bay. The longitudinal portion of this creek was originally undoubtedly the subsequent branch of a consequent stream, and has been captured by the headwater erosion of what is now a lower part of Pilarcitos Creek. This capture transferred the divide from Montara Ridge to Cahill Ridge, and is doubtless due to the steeper grade on the ocean side of the fault block. The Almshouse Canyon, on the east side of Las Pulgas Ridge, is also genetically a subsequent stream, but has a special history. A large alluvial cone dejected from the transverse canyons of Montara once obstructed the channel of Crystal Springs Creek, just where the dam now is, between Upper and Lower Crystal Springs lakes. This cone ponded back the waters of Crystal Springs coming from the south. At this time Almhouse Creek was but a small subsequent stream. The ponded waters reached its divide, and its functions became at once increased. The little lateral canyon became the aqueduct for the conveyance of the waters of Crystal Springs to San Mateo Creek in place of the channel dammed by the alluvial cone. The canyon became enlarged disproportionately to its length. Afterwards the alluvial cone was broken down by headwater action on the north side, Crystal Springs Creek resumed its old course, and the Almhouse aqueduct became defunct, leaving the canyon as proof of its former existence. The alluvial cone still remains, and was utilized in making the dam of the reservoir now known as Upper Crystal Springs Lake. At the time that this cone encroached on Crystal Springs Creek the bottom of that creek was much lower than the bed of the Almshouse Cañyon.

An interesting case of drainage may be mentioned on the southwest side of Montara. It is that of the creek which enters the ocean at Montara Point. This creek cuts through an isolated ridge of granite 300 feet high close to the shore. The only possible explanation of the apparent anomaly is that it is a superimposed stream. One other interesting and quite modern feature of the drainage is the capture of the upper reaches of San Andreas Creek by the headwater erosion of San Bruno Creek below the Jersey farm.

The drainage of the slopes below the Buri-buri plateau appears to be essentially consequent, with tendencies to subsequent branching. On the southwest side of Merced Valley this drainage is scoring and trenching the hills in a most remarkably vigorous manner. Very narrow, deep, pinnacled canyons and cirque-like amphitheaters with precipitous sides are the results of the most modern action, and the numerous valleys of this slope are doubtless the degraded and softened products of similar canyons and cirques of older date.

When we come to the bottom of Merced Valley the drainage is again longitudinal or parallel to the strike of the tilted blocks, being consequent upon the structure of the valley. The drainage runs both ways from the vicinity of Colma. The discharges of the two streams are, however, in strong contrast. That flowing toward the bay discharges upon the tidal flats and loses its identity in the tidal channels. The other, flowing toward the ocean, discharges into Lake Merced. This lake is a remarkable feature of the topography. It lies in a depression which is a structural valley and which is separated from the ocean by a very narrow ridge. Though thus lying in a structural valley, the form of the shore contours of the lake, the stream cliffs by which it is bounded, and its relation to the drainage of the valley all demonstrate that the immediate basin of the lake is a drowned valley of stream erosion.

The bottom of Lake Merced is 10 feet below sea-level, and this fact demonstrates a recent submergence. The drowned valley undoubtedly once had free access to the ocean at tide level, but sand dunes choked the channel and dammed back the waters till they stood 10 feet above tide. Since then the lake has been artificially raised another 10 feet. The extent of this submergence is very probably measured by the depth of the channel at the Golden Gate. The question is discussed by the



MERCED VALLEY FROM THE SLOPES OF SAN BRUNO MOUNTAIN, SHOWING LAKE MERCED.

writer in another paper.[1] The lake is certainly one of the most recent topographic features of our field, and suggests that subsidence is now in progress.

DELTAS AND SHORE FEATURES.

Alluvial fans are features of the lower slopes. The number of small transverse streams which are cutting back into the northeastern edge of the Buri-buri plateau is very large, and the fans which are being built up at the mouths of the canyons overlap. There is only one large fan or delta which merits special mention. It is the broad low delta of San Mateo Creek, which runs out to the shore of the bay and prevents the extension of the tidal marsh along this part of the shore. The small streams assist in the development of the tidal marsh. The large one, by depositing more sediment than the tidal streams can distribute, has in part prevented the formation of the marsh and in part buried that already formed.

The tidal marsh is the feature of the bay shore which is most in contrast with that of the ocean shore, and must be regarded as an embryonic constructional or block feature of the topography. It seems to owe its existence to the deposition of the sediments with which the bay water is heavily charged in rainy seasons along the shore where the tidal and other currents are checked. At very high water, when the marsh is partially flooded, the flood water, coming from the bay and laden with sediment, is filtered by the vegetation of the marsh, and so adds to its surface up to the limit of extreme high water. As the marsh is in places some miles wide its perfectly level character, with the tidal streams extending quite to its rear, indicates that there has been no very recent uplift of the land. On the other hand, the marsh might have been developed to its present condition during a moderate subsidence if the rate of accumulation of tidal silt on its surface were equal to the rate of subsidence.

The topographic features of the peninsula which are due to the destructive forces of the present strand are chiefly interesting from the contrast which they present on the two sides of the peninsula. On the ocean side there has been a vigorous development of sea-cliffs, and the simplification of the shore contour is due chiefly to this process. On the bay side the development of sea-cliffs has been comparatively feeble, and the simplification of the shore contour, so far as it has been effected, is due to the formation in the bay of the tidal marshes above referred to. This process toward the north end of the peninsula has not been so effective as that due to the recession of cliffs on the ocean shore, so that the shore contour of the bay side of the peninsula is more intricate than on the ocean side. The most notable instance of the truncation of a projecting ridge by wave action is that exhibited by the cliffs south of Point San Pedro. These cliffs attain a height of

[1] The Geomorphy of the Coast of Northern California. Bull. Dept. Geol. Univ. Cal., Vol. 1, No. 8.

900 feet, and form the terminal revetment of Montara Ridge on the ocean. The sea-cliffs which rise above the beach between Lake Merced and Mussel Rock are receding rapidly, and the curve of the shore contour is evidently in a very stable condition. The curious convexity of this curve opposite Lake Merced appears to be dependent upon the structure of the strata, and will probably persist for some time as the shore-line advances inward. The shore-line from the outlet of Lake Merced to the Cliff House is entirely simple. It has the appearance of an embayment which has been filled in by the drift from the cliffs to the south. This suggestion is difficult of investigation by reason of the sand dunes which extend from the shore inward; but it is improbable that it is such an embayment in the sense of ever having been a bay of the present strand. Beneath the sand dunes are the bedded sands of the Terrace formations, and this low beach has very probably a true sea-cliff behind it, although degraded as fast as formed by the wind and concealed by the dunes. From San Pedro Point to the Cliff House there is little intricacy in the shore-line, the few bays which exist being well filled with drift from the cliffs. From San Pedro Point to Pillar Point the cliffs are in active recession, but nowhere is this more apparent than along the Pillar Point Ridge. Here a broad wave-cut terrace may be seen in process of evolution. The strata are folded into interlocking anticlines and synclines, and at low tide the truncation of the anticlinal domes is very apparent for several hundred yards out from the base of the cliffs. In general, the tendency which is active for the simplification of the shore contour on both the ocean and the bay side of the peninsula is to a certain extent counteracted by the recent submergence.

PRELIMINARY REPORT

ON THE

MARQUETTE IRON-BEARING DISTRICT OF MICHIGAN,

BY

CHARLES RICHARD VAN HISE

AND

WILLIAM SHIRLEY BAYLEY,

WITH A CHAPTER ON THE REPUBLIC TROUGH,

BY

HENRY LLOYD SMYTH.

CONTENTS.

ILLUSTRATIONS.

THE MARQUETTE IRON-BEARING DISTRICT OF MICHIGAN.

By Charles Richard Van Hise and William Shirley Bayley.

INTRODUCTION.

This report is a preliminary account of the Marquette district, the oldest important iron-producing area of the Lake Superior region. Already two detailed reports have been issued upon it by the Michigan State survey. The first, by Maj. T. B. Brooks, published in 1873, was a faithful account of the structural and economic geology of the part of the district producing iron ore at that time, no attempt being made to completely map the area. The intrusive character of most of the greenstones and the physical break existing between the Upper Marquette and Lower Marquette series were not recognized. While for closely studied localities Major Brooks's mapping is remarkably accurate, it was not possible under the circumstances to correctly determine the general succession. The second report, by Dr. Carl Rominger, was published in 1881. This report is accompanied by an areal map of the district from Lake Superior to 1 mile into range 28 west. The topography is carefully indicated by hachures, and the areal distribution of the more important formations is delineated with a fair degree of accuracy, showing that the district had been traversed with great patience. However, all quartzites are placed together, without reference to their age, and the same is true of the slates. The map is not accompanied by any sections. It is therefore to be considered as a lithological rather than a structural map. Many other papers, of greater or less importance, have been published upon the Marquette district, by Wadsworth, Irving, Pumpelly, and others. In our final monographic report the first chapter will be devoted to a full summary, not only of the reports of Brooks and Rominger, but also of all other publications concerning the district. In this paper lack of space makes this impossible.

The present report is based upon a detailed examination of the entire Algonkian area from Lake Superior to Michigamme. Topographic maps of a part of the district made by the U. S. Geological Survey have been supplemented in critical areas by large-scale plane-table sheets. Practically all outcrops have been accurately mapped on a large scale. In the mining part of the area advantage has been taken of underground workings and borings. Owing to the detailed character of this work, combined with the advance of geological knowledge in the past twenty years, it is now possible to present a much more satisfactory account of the structure of the district than has yet been given.

The field work upon which the present report is based has been done by W. N. Merriam, W. S. Bayley, H. L. Smyth, J. Morgan Clements, James R. Thompson, and C. R. Van Hise, although Mr. Bayley has taken a larger part of the mapping than anyone else. Several others have rendered subordinate assistance. The detailed mapping of the area from west of the center of range 28 west to Michigamme is mainly the work of Mr. Merriam. He also studied the Republic tongue, but his work in this part of the area has been supplemented by a much more detailed study by Mr. H. L. Smyth. From the center of range 28 west to the center of range 27 west, the mapping is partly the work of Mr. Merriam and partly that of Mr. Bayley. East of the center of range 27 west to Lake Superior the mapping has been done mainly by Mr. Bayley, although Mr. Clements assisted one field season. Mr. Smyth mapped the Republic tongue and the area to the west. All the underground work in connection with the mines was done by Mr. Thompson. Mr. Van Hise's part of the task has been the structural study of the entire district, to which he has given one entire field season and large parts of several others.

Notwithstanding the fact that mining has been done for many years in the district, it is little traveled away from the roads. The timber has been cut off for iron smelting. Where the cut was comparatively recent the fires have run, and there is now a tangle of fallen timber and briars and bushes. Where the cut is older there is a thick second growth, 20 to 50 feet high. The area is therefore much more difficult to penetrate than was the primeval forest. Moreover, the bushes are an effectual bar to extended vision, except from rocky points. While the district is not mountainous, in detail much of it is exceedingly rough, so that in traversing parts of it one is nearly always ascending or descending a steep slope. Other parts are covered by a mantle of glacial deposit, through which the rocks rarely protrude. Because of the irregularity of the topography and the difficulty of seeing, it has been impossible to base locations on the ordinary topographic maps. For the larger part of the district locating was done either with the aid of the plane table or by pacing from section corners and quarter posts. The rocks of the district comprise three series, separated by unconformities. Each of these series consists of several formations. The transgression of the sea did not occur over the entire district at the same time, so that in parts of it the succession is not complete; and in other parts the succession is incomplete because of intervening erosion. Finally, the district has been folded in a complicated fashion in two directions, with resulting profound metamorphism.

It is plain from the foregoing that the district is one of exceeding difficulty, and that it has been possible to unravel its intricacies only by patient and laborious work. The petrographical and chemical study is far from complete. Further work may alter some of the minor conclusions of the following report, but it is believed that the larger results will not be greatly modified.

GENERAL GEOLOGICAL MAP OF THE MARQUETTE DISTRICT.

BY C. R. VAN HISE AND W. S. BAYLEY.

SCALE, 1 INCH = 1 MILE. CONTOUR INTERVALS, 50 FEET.

POST ALGONKIAN	ALGONKIAN											ARCHEAN				
	IGNEOUS		UPPER MARQUETTE				LOWER MARQUETTE					NORTHERN AND SOUTHERN COMPLEX				
	UNCLASSIFIED	DIABASE AND DIORITE	MICHIGAMME FORMATION	ISHPEMING FORMATION	CLARKSBURG FORMATION	NEGAUNEE FORMATION	SIAMO SLATE	AJIBIK QUARTZITE	WEWA SLATE	KONA DOLOMITE	MESNARD QUARTZITE	GRANITE	PALMER GNEISS	KITCHI & MONA SCHISTS	PERIDOTITE	SYENITE
PA	AU	Aid	Aum	Aui	Auc	Aln	Als	Ala	Alw	Alk	Alm	gr	pg	ks m.s.	p	sy

JULIUS BIEN & CO. LITH. N.Y.

In the preparation of the manuscript, Chapter I, upon the Basement Complex, is by W. S. Bayley; Chapter IV, upon the Republic Trough, is by H. L. Smyth; Chapters II and III, upon the Algonkian, and Chapter V, upon the general geology, are by C. R. Van Hise.

The map (Pl. XIII) is the generalized results from large detailed plats upon the scale of 4 inches or 8 inches to the mile. The formations were outlined by putting together the data furnished by the different outcrops, which in much of the district are separated by the drift. It follows that the boundary lines between the formations are frequently not accurate in detail. Where exposures show the actual contact, the boundary lines are solid; in other cases, where they may vary from the positions indicated, the lines are dotted. If the map be compared with that of previous reports, it will be found that the iron formation is extended at various places beyond the areas heretofore considered as belonging in this belt. The principle followed is to consider the iron formation as extending in its proper place between the other formations unless there is positive evidence to the contrary. It is probably true that at various places where the Negaunee formation appears on the map, west of the center of range 28 west, it has been entirely removed for greater or lesser distances by the Upper Marquette erosion.

Accompanying the final report it is designed to publish an atlas on the scale of 4 inches to the mile, which shall show the actual positions of all exposures, and thus the mining men will be able to judge as to the accuracy of the boundary lines between the formations, and hence as to the areas where ore deposits may possibly occur.

The Algonkian of the Marquette district is divisible into two series, presumably the equivalents of the Lower Huronian and the Upper Huronian of other districts of Lake Superior and of the Original Huronian of Canada. These two divisions are separated by an unconformity. In this paper the lower clastic series of the Marquette area will be called the Lower Marquette series, and the upper the Upper Marquette series. The Algonkian rocks are bounded on the north and on the south by the Basement Complex, or Archean. The Archean areas consist of an intricate mixture of granites, gneisses, schists, and surface volcanics. All are thoroughly crystalline.

The Lower Marquette series covers the larger part of the area of Algonkian rocks east of Ishpeming, and forms belts on the north and south sides of the Algonkian area west of Ishpeming. The easternmost Upper Marquette rocks appear at Negaunee and at Palmer. Here, however, they are in patches, the east end of the main area appearing at Ishpeming. From this place the Upper Marquette rapidly widens. At Lake Michigamme the Algonkian expands into a broad area, from which several arms extend. In each of these arms the lower series occupies the outer borders of the Algonkian belts, the upper series appearing in the centers of the tongues.

The area discussed in the present paper is limited on the west by the east mile of range 31 west, and on the south by township 46 north, with the exception that the southern extremity of the Republic tongue extends into township 45 north. The Algonkian rocks of this area, speaking broadly and generally, are in a great synclinorium. This synclinorium is of a peculiar and complicated character, which will be fully considered later. It is sufficient here to say that in the center of the area the rocks in the outer borders of the Algonkian belt are in a series of sharply overturned folds. The Algonkian rocks have apparently been thrust over the more rigid Archean granite, and, as a consequence, on each side of the Algonkian trough a series of overfolds plunge steeply toward its center, producing a structure resembling in this respect the composed fan structure of the Alps. There is, however, this great difference between the Marquette structure and that of the Alps, that in passing from the sides of the trough toward the center newer rocks appear rather than older ones, so that in the center of the synclinorium the youngest rocks are found. It is as if the composed fan folds of the Alps were sagged downward, so that the structure as a whole is a synclinorium rather than an anticlinorium. The structure thus differs from the composed fan structure of the Alps and from the inverted intermount trough of Lapworth, and may be designated for the present the Marquette type of fold (fig. 9). This

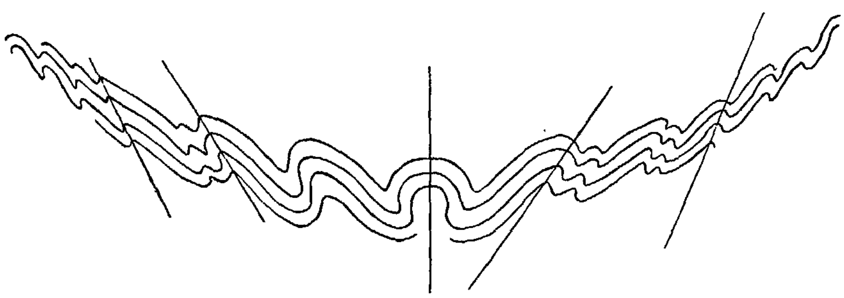
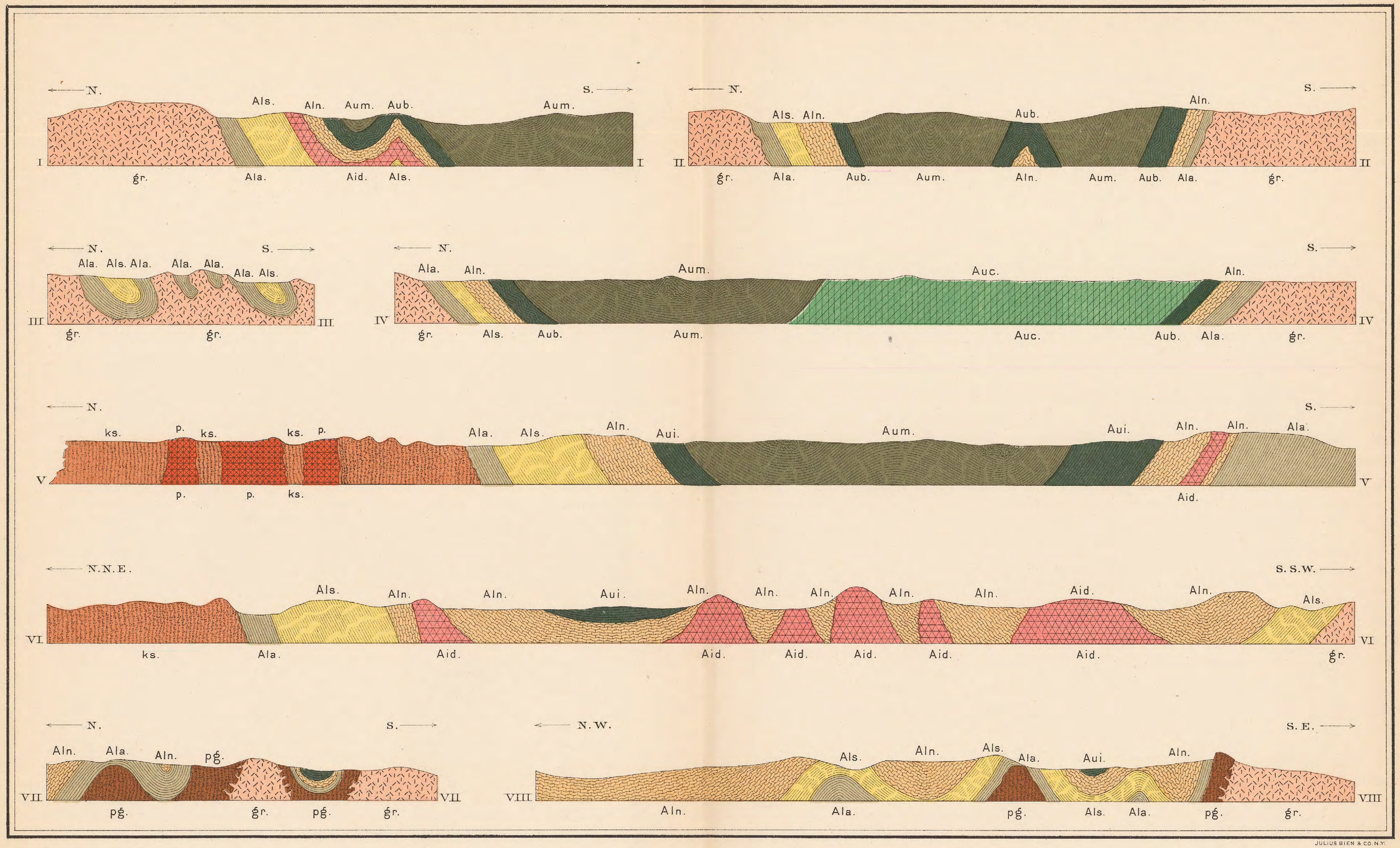


FIG. 9.—Generalized cross-section of Marquette synclinorium, showing the Marquette type of fold.

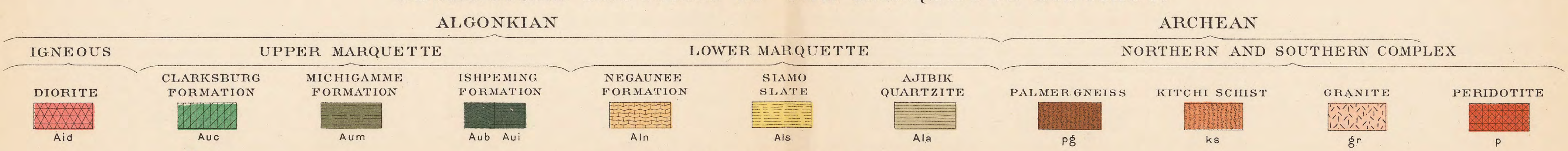
structure prevails in the central part of the area from Ishpeming and Negaunee westward to Clarksburg, but it does not extend to Lake Superior on the east nor to Lake Michigamme on the west.

While the more conspicuous folds have in general an east-west direction the rocks have also been under strong east-west compression, as a consequence of which the folds are buckled so that they often show a steep pitch. In places the north-south folds become more prominent than the east-west folds, and control the prevalent strikes and dips. In an intermediate area the two series of folds are about equally important, thus producing most irregular strikes and dips. These north-south folds are of two orders, the first of great magnitude but small dip, the second, superimposed on the first, of less length of wave but with steeper dip.



JULIUS BIEN & CO. N.Y.

GEOLOGICAL SECTIONS OF THE MARQUETTE DISTRICT.



Horizontal Scale, 2 in. = 1 mile. Vertical Scale, 1 in. = 1320 feet.
Elevation of Base Lines, 1000 feet.

CHAPTER I.

THE BASEMENT COMPLEX.

Below the Algonkian deposits of the Marquette area are schistose and massive phases of crystalline and pyroclastic rocks, so different from the Algonkian sediments that there is rarely any difficulty in distinguishing between them and the clastic rocks above them. These inferior rocks are unconformably below the lowest members of the Marquette series. It is probable that they embrace members of widely different ages, but up to the present time no separation of the schists into sharply defined subgroups upon the basis of age has been attempted, because of the complexity of the relations existing between the various rock types, due largely to the many vicissitudes through which they have passed.

The work in the pre-Marquette areas of Michigan is far from complete, as the study of the district was primarily directed to the Algonkian series, and time has not yet permitted a full investigation of the material collected from the older areas.

In consequence of the widespread occurrence of these rocks, and the complexity of their structural relations, the term "Basement Complex" has been used to designate the rocks upon which the sedimentary deposits have been laid down. They are believed to be a part of the Archean. This Basement Complex in the Marquette district, as elsewhere, consists of a series of schists and gneisses of varying acidity, cut by veins and dikes of granite and other acid rocks, dikes of basic eruptives, and bosses of basic, intermediate, and acid materials. So different are they from the members of the Marquette series in appearance, structure, and composition, that even where there is no apparent structural break between the two series they would naturally be regarded as of different ages, or at least as having been produced under very different conditions. It is partly for the purpose of contrast with the descriptions of the Algonkian rocks that the members of the Basement Complex are here described.

The Marquette rocks are bounded both to the north and to the south by areas of the Basement Complex. The northern area of these rocks differs from the southern area in the nature of its rock material, and so the two areas are discussed separately. In addition to these two large areas, there are smaller ones that are entirely surrounded by the Algonkian beds, like islands in a sea of rocks. In these areas the rocks are not materially different from those of the larger areas, but for the sake of clearness in picturing the structure of the Marquette district, they will be referred to separately.

SECTION I. THE NORTHERN COMPLEX.

Throughout nearly its whole extent, from Lake Superior as far west as beyond Lake Michigamme, the Marquette series is limited on the north by a belt of crystalline and pyroclastic rocks, cut by basic, intermediate, and acid dikes and bosses and by granite veins. Near Lake Superior the two series are separated by a small area without outcrops, except occasional ledges of Potsdam sandstone. Whatever rocks may underlie this area, they are buried deep beneath Pleistocene sands and gravels. Elsewhere the two series are practically in contact, and at many places their actual contacts may be seen.

The rocks comprising the Northern Complex are gneissoid granites, syenites, greenstone-schists, peridotites, aplites, vein granites, diabases, diorites, and epidiorites. The first three are often highly foliated, while the last six are massive, or but slightly schistose. The former occupy the greater portion of the belt, so far as it is within the limit of the map (Pl. XIII), and are older than the latter, which cut them in the form of dikes and bosses.

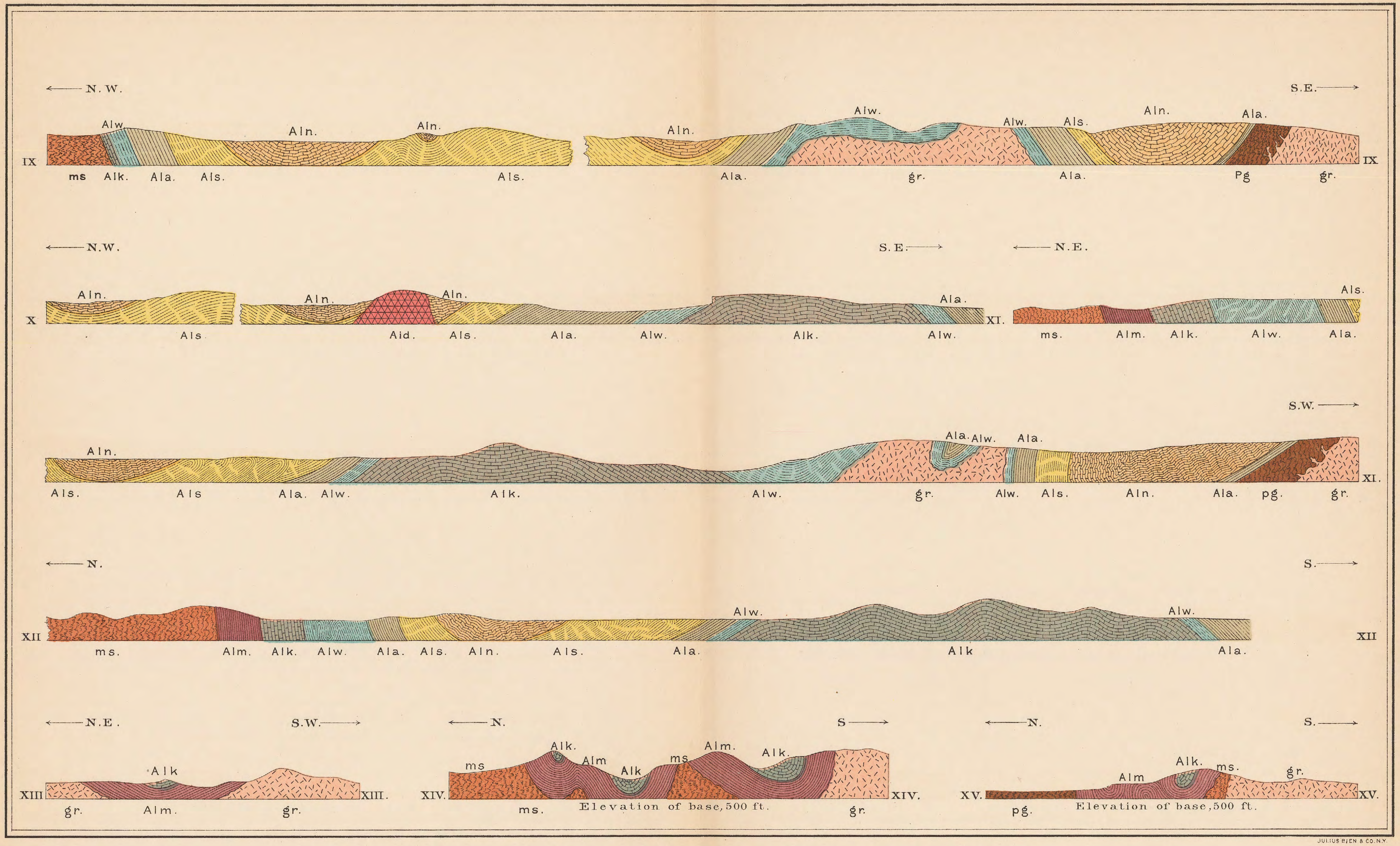
The foliated rocks occupy areas whose boundaries are not so well defined as is the case with the Marquette fragmentals, since the schists and granitoid gneisses and syenites gradually pass into one another, through the intrusion of the basic rocks by dikes and veins of the acid ones. Nevertheless, an attempt has been made to map these areas. In their interiors the different phases of schists, granites, and syenites are well characterized, but on their peripheries there is always a complex mixture of the various schists with one another, or with the granitic rocks. The respective colors on the map are believed to cover the areas within which the corresponding rocks predominate largely over other rocks. The boundary lines separating the different areas are drawn at about the places where the different varieties are found in approximately equal quantities.

The greenstone-schists include two classes. The first are nonconglomeratic green schists. These are called the Mona schists, because good exposures are found on hills of this name southwest of Marquette. The second contain pebble-like bodies, and these are discussed separately. Their best development is on the Kitchi Hills, in the neighborhood of Deer Lake, northwest of Ishpeming, and hence they are called the Kitchi schists.

THE MONA SCHISTS.

DISTRIBUTION AND TOPOGRAPHY.

The Mona schists occupy the eastern portion of the Northern Complex, extending westward from Lake Superior on the east to about the west line of range 26 W., where they are replaced by the Kitchi schists. In its eastern portion the area stretches northward a mile beyond the northern limit of the accompanying map to a great area of gneissoid



GEOLOGICAL SECTIONS OF THE MARQUETTE DISTRICT.

ALGONKIAN

IGNEOUS

- DIORITE — Aid

LOWER MARQUETTE

- NEGAUNEE FORMATION — Aln
- SIAMO SLATE — Als
- AJIBIK QUARTZITE — Ala
- WEWE SLATE — Alw.
- KONA DOLOMITE — Alk.
- MESNARD QUARTZITE — Alm.

ARCHEAN

NORTHERN AND SOUTHERN COMPLEX

- PALMER GNEISS — pg
- MONA SCHIST — m.s.
- GRANITE — gr

Horizontal Scale, 2 in. - 1 mile. Vertical Scale, 1 in. - 1320 feet.
Elevation of Base Lines, 1000 feet.

granite, which is similar in its characteristics to the granites farther west. A mile west of the west line of range 25 W. the belt narrows, and has a width of only 1½ or 2 miles. Here it is bounded on the north by a narrow belt of coarse red syenite, lying partly within the limits of the map. On the south the schists are in contact with the transgression quartzite of the Lower Marquette series throughout their entire extent, except toward the east, where they pass beneath the Pleistocene deposits bordering the lake.

The topography of the area is, in a minor way, rugged in the extreme. Large and small hills of the schists rise with rough, precipitous faces above the level of the surrounding country, and lift their smooth, glaciated heads from 200 to 900 feet above the waters of Lake Superior. When the hills are low their tops only project, as smooth, round knobs, above the drift deposits surrounding them. (Pl. XVI.) The higher hills are composed of groups of these knobs raised high above the valleys between them. Their sides are ragged and rough, or smooth and vertical, and their tops are groups of rounded knolls.

RELATIONS TO SURROUNDING ROCKS.

It has already been stated that the green schists pass gradually into the gneissoid granites to the north through the intrusion of the former by apophyses of the latter. In referring to this contact Dr. Williams writes.[1] "There is no such sharp line of contact as is represented on Rominger's map, but, on the contrary, as Rominger himself explains, there is a complete interpenetration of the two rock masses. The granite has intruded itself into the schistose greenstones, for the most part following their bedding and forcing apart their strata. The amount of the acid rock gradually diminishes as we go southward." At a greater or less distance from the contact it is completely absent, and the green schists occur alone, except for the dikes of aplite and diabase that everywhere cut through them—as well as through all other members of the Basement Complex—and the narrow bands of acid schists with which they are interlaminated.

The stratigraphic separation of the Mona schists from the Kitchi formation to the west has not yet been possible. In passing from the former area into the latter, beds of the conglomeratic schists are found more and more frequently between those of the nonconglomeratic kinds. As we shall see later, many of the Mona schists are probably altered tuffs, while others are squeezed basic lavas. A sharp line of demarcation between these rocks and the tuffaceous greenstones of the Kitchi formation to the west is therefore not to be expected, for the former are probably only much metamorphosed phases of rocks like the latter.

From the Algonkian beds to the south the schists are separated by conglomerates and great unconformities. In the conglomerates

[1] The Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan, by G. H. Williams. Bull. U. S. Geol. Surv. No. 62, p. 146, 1890.

large bowlders of the schists are often found; consequently there can be no question but that the latter rocks were consolidated and had been made schistose before the basement beds of the overlying clastic series were laid down upon them.

The Mona schists are therefore older than the granites of the Basement Complex. They are of about the same age as the rocks of the Kitchi formation, which are probably their western equivalents; they are pre-Algonkian.

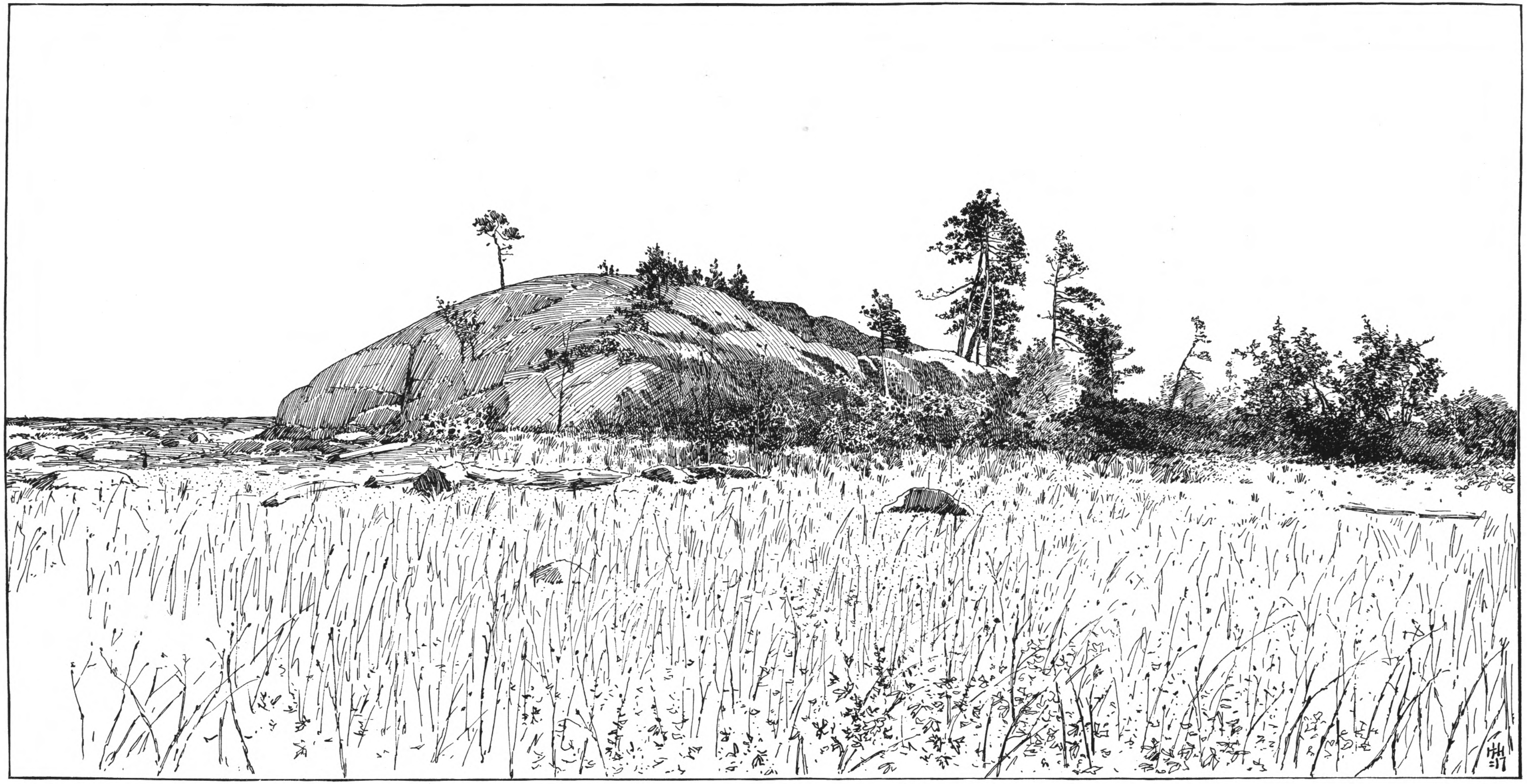
VARIETIES, PETROGRAPHICAL CHARACTER, AND ORIGIN.

The structure of the schists varies within wide limits. Sometimes the rocks are very fine grained and as fissile as slates; at other times they are coarser grained and fibrous, when they are distinctly foliated; again, they may be very coarse grained and fibrous, but possessed of only indistinct foliation; and, finally, they may be dense and apparently quite massive. In the latter case they always yield to fracture much more readily in one direction than in others, and under the microscope are seen to have a schistose structure in thin section. The schistosity of all the well-foliated varieties dips at high angles, and strikes nearly east and west, approximately parallel to the trend of the Marquette trough.

Dr. Williams, who has studied the greenstone-schists of this area in detail, divides the eastern portion of the area into a northern and a southern half—in the former of which banded schists prevail; in the latter, aphanitic varieties. In neither half, however, are the rocks of either variety excluded by those of the other. Farther west the dense and the banded fibrous schists are associated in the most intimate manner.

The aphanitic schists have a light-green color, sometimes shading to a grayish or pinkish green, and a uniformly fine grain. Occasionally their texture is so fine that hand specimens resemble greenish cherts in appearance, or massive graywacke-like sediments. In the ledge the rocks present a rudely schistose structure, which is lost in the specimens. In some exposures, as in the knob in the NE. ¼, NW. ¼, sec. 28, T. 48 N., R. 26 W., the rock mass is divided into oval or lenticular areas, separated from one another by schistose material of the same nature as in the oval masses but of much finer grain. This structure is neither concretionary nor agglomeratic. It is similar to the structure of certain Saxon schists which Rothpletz has shown to be mechanical in origin.

In thin section the aphanitic schists are found to be nearly as uniform in composition as they are in appearance. They consist of granular epidote, small flakes and needles of chlorite and hornblende, and altered plagioclase, with the addition usually of calcite, leucoxene, a little quartz, and mosaic areas of albite or quartz. The plagioclase may sometimes be detected in small lath-shaped crystals, lying in all azimuths



KNOB OF GREENSTONE SCHIST NEAR THE MOUTH OF DEAD RIVER, NEAR MARQUETTE, MICHIGAN.

amidst the other components, but more frequently the mineral is so much decomposed that its original form can no longer be recognized. The epidote grains are usually scattered through the slide. Not infrequently, however, they are aggregated into little groups with the cross-sections of feldspars. The plates and needles of chlorite and the needles of hornblende, which are rather abundant in some sections of the rocks, are quite small. They are intermingled with a few sericite flakes, a little calcite, and small areas of the clear mosaic already referred to. Together these constituents inclose the leucoxene and the altered plagioclase crystals in the same way as glass incloses the crystal components in a glassy basalt. In other cases the use of crossed nicols will bring out an arrangement of the various constituents in such a way as to resemble the structure of fine-grained diabases, and even of gabbros. In still other instances, in the apparently heterogeneous aggregate of components, under crossed nicols a structure resembling that of tuffs is discerned, in which broken pieces of altered plagioclase are discovered in a fine-grained matrix with no well-defined structure.

The composition of these rocks is that of altered diabases or basalts. Their structure, where it can be detected, is that of basic lavas or of tuffs. It is probable, as Williams has already observed, that these dense epidotic greenstone schists are metamorphosed lavas and tuffs. Their schistosity is due to the tendency of the chlorite particles to lie with their long axes in a common direction. This phenomenon is explained on the supposition that it is the result of shearing, which is also responsible for much of the alteration to which the original rocks have been subjected.

Many of the dense schists have been weathered until they now consist largely of calcite and epidote, so that no evidence of their original character remains.

The banded schists, best exposed in the northern portion of the area, are composed of alternate layers of darker and lighter shades of green, which gives these particular greenstones a striped appearance. Their texture is much coarser than that of the aphanitic greenstones described above, and their structure is characteristically schistose. They all contain an abundance of secondary amphibole, and consequently they are all more or less fibrous. When their fibrosity is pronounced and their schistosity marked, they form very fissile schists. When the schistosity is less marked, the rocks may still be fibrous, but the fibers are grouped around centers scattered through the specimen, and the rock has the aspect of a uralitized diabase or gabbro.

On account of their banded character these schists have been regarded as sedimentary by nearly all geologists who have studied them. "The alternation in the color and composition of the layers is so frequent and so constant, and their parallelism to the east and west strike of all the rocks of this neighborhood is so exact," writes Williams, "that no hypothesis of their originally massive character will satisfactorily account for the observed facts. On the other hand, the chemical and the microscopical characters of these schists agree closely with those of associated massive greenstones which are known to have been derived by the alteration of basic eruptive rocks."[1] Normally these schists show in thin section large or small sheaf-like bundles of bluish-green hornblende scattered through the slide indiscriminately, or aggregated into groups, with irregular outlines and frayed edges, and imbedded in a groundmass consisting of much decomposed plagioclase and a mosaic of colorless grains of albite and quartz. With the hornblende chlorite is frequently associated, the areas occupied by the two minerals sometimes having the outlines of an amphibole or a pyroxene crystal. A great deal of leucoxene is observed in most sections, and not infrequently granular epidote is intermingled with the components of the mosaic. In addition to these substances, which are well defined, there are certain obscurely outlined plagioclases, which present between crossed nicols the shapes of sharp-edged fragments. In none of the slides of these rocks has anything been detected that may be regarded as a waterworn sand grain.

The plagioclase of these rocks, whether in the fragments or in the indefinite areas that serve as a sort of groundmass to much of the hornblende, is altered to epidote, sericite, chlorite, and calcite. The mosaic filling the interstices between everything else is in all probability secondary, as it not infrequently fills little cracks in the schists, forming veinlets. This mosaic is like that described by Lossen[2] in the schistose diabases of the eastern Harz, which have been shown to owe their foliation to pressure.

The Marquette banded schists show the structure sometimes of massive rocks and sometimes of pyroclastic ones; but more frequently they exhibit no structure from which their origin can be inferred. Their composition, however, is that of diabases. Their field aspects are very different from those of most schistose diabases. The rocks are banded, like sedimentary ones. A possible explanation of these opposite sets of characters is that the rocks exhibiting them are water-deposited clastics of volcanic origin, like the tuffs of modern volcanoes, that have been tilted from their original position and have been rendered schistose by pressure, as have many of the dike masses that intrude them. They possess many of the characteristics of dynamically metamorphosed tuffs, and others due to weathering processes.

In addition to the aphanitic schists and the banded schists of this area, there are three other phases. The first phase strongly resembles schistose varieties of the dike rocks to which the name "epidiorite" has been given. These rocks probably represent the coarser lavas that were associated with the glassy and fine-grained lavas and the tuffs that

[1] The Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan, by G. H. Williams. Bull. U. S. Geol. Surv. No. 62, p. 154, 1890.

[2] Zeitschr. deutsch. geol. Gesell., Vol. XXIV, 1872, p. 730; Jahrb. k. preuss. geol. Landesanstalt, 1883, p. 640; 1884, p. 528.

gave rise to the more common types of schist in the district. In the second phase the structure is plainly diabasic, but the quantity of hornblende is so great that the rocks might well be called amphibolites. The third phase is more nearly like the true crystalline schists than are any others of the greenstone-schists. This is the least common type of the green schist area, and appears to be limited to its northern portion. In the hand specimen the rocks of this type are dark-green in color, very fine in grain, and extremely schistose. Under the microscope they appear to be much fresher than the other green schists. They are composed almost wholly of long, narrow prisms and needles of light-green hornblende, lying in a mass of tiny, clear grains of plagioclase, which interlock in the manner of the grains of a crystalline schist. Intermingled with these clear feldspars are a few larger grains of reddish, altered ones, clouded by inclusions of epidote, kaolin, and sericite. On their edges some of these seem to be passing into the clearer, fresher-looking feldspar, which is no doubt a new product, derived from the plagioclase of an older rock. Epidote and leucoxene are both present. The former, however, is often in the large greenish plates so common in hornblende-schists. It is impossible at present to decide whether these schists are squeezed tuffs or squeezed lavas. They are no doubt pressure schists derived from volcanic material of some kind, and not from true sediments, which should contain quartz.

ACID SCHISTS.

In a number of places within the area of the Mona schists the green schists are associated with light-colored rocks that are very like certain schistose acid dikes that cut across the greenstones. There is great difficulty in determining whether these light schists were derived from eruptive porphyries or from their tuffs. In many cases the latter is supposed to be the case. The larger decomposed fragments that lie in the fine-grained groundmass of these rocks are so badly shattered, and the different pieces near together fit into each other so imperfectly, that it would seem hardly possible that they could be fragments produced by the crushing of a crystal. Besides, these white or pink schists and the green ones occur side by side in the same ledge, and the two apparently grade into each other.

In many of the sections cut from these rocks only quartz and sericite, with perhaps a little epidote, can be discovered. The three minerals form a very fine-grained aggregate, resembling strongly the mosaic of many devitrified rhyolites. The tiny quartz grains are separated from one another by flakes of sericite, arranged with their longer axes in a single direction. At present the rocks are sericite-schists. In a few of them obscure traces of feldspathic fragments may be detected, when their sections are examined with low powers between crossed nicols, but from most of them every trace of fragmental material has disappeared and the rocks are now thoroughly crystalline.

Schists like these have been described by Williams,[1] who regards them as metamorphosed acid tuffs. They may possibly have been acid sheets interstratified with the basic lavas and tuffs that formed the greenstones, but when the fact is considered that they grade imperceptibly into the green schists, and that in some of them traces of fragments may be recognized, it seems more probable that they were, as Williams supposes, originally acid tuffs, which have been altered and made schistose by the same processes that changed the diabasic lavas and tuffs into the greenstone-schists.

THE KITCHI SCHISTS.

Many of the green schists of the Northern Complex are noticeable for the pebble and bowlder-like bodies scattered through them. These fragments stand out so plainly in the weathered surfaces of the exposures on the Kitchi Hills in the vicinity of Deer Lake that they may be seen at long distances. They are usually so well rounded that the rock containing them looks very much like a sedimentary conglomerate. Indeed, so conglomeratic are their features that they have frequently been called the Deer Lake conglomerates. (See Pl. XVII.) The rocks are plainly basic tuffs, but they have preserved their tuffaceous character so much more perfectly than have the banded varieties of the Mona schists, from which they differ also in composition, that they have been designated by the distinctive name Kitchi schists.

DISTRIBUTION AND TOPOGRAPHY.

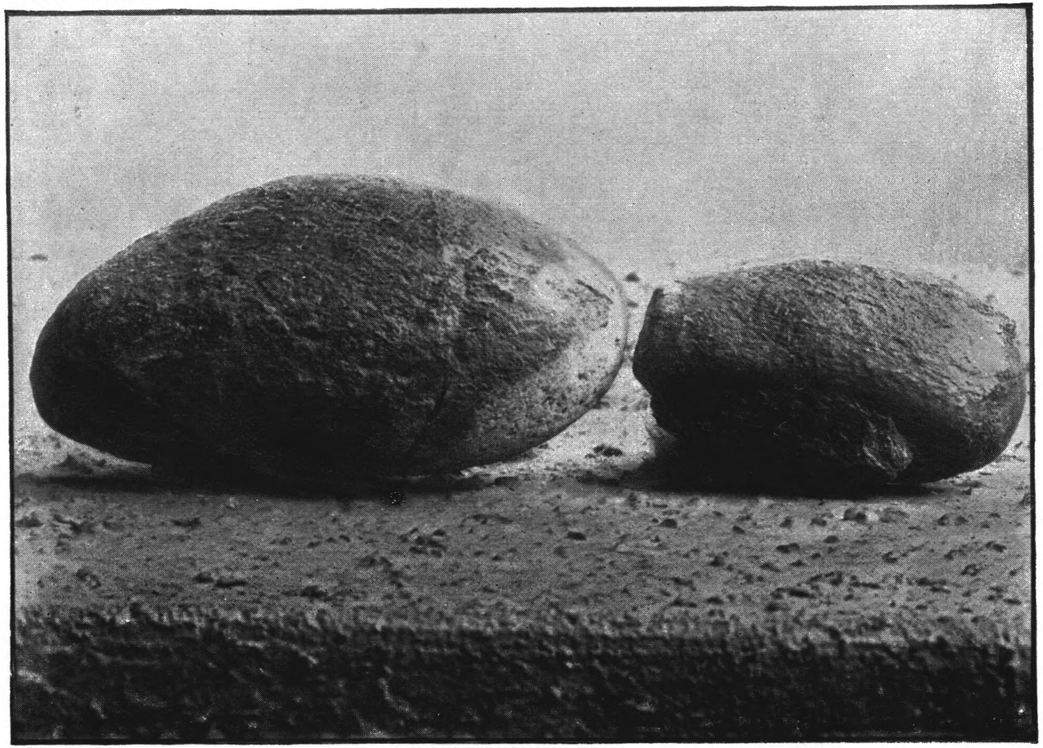
The Kitchi schists occur just west of the Mona schist area, stretching from the east line of range 27 W. to the west line of secs. 25 and 36 in T. 48 N., R. 28 W., with a width varying from 2 miles to 3½ miles. At the west end the schists are in contact with a coarse gneissoid granite. Both to the north and to the south the "conglomerate" area is bounded by Algonkian deposits; on the north by those belonging to the Silver Lake area, and on the south by those of the Marquette range.

The topography of the country covered by these rocks is not very different from that of the area of the Mona schists. Isolated, rounded knobs are not so frequent in the area of the "conglomerates," but the larger hills have the same character in both areas. Drift is less thick in this district than in that of the Mona schists, the larger hills being more commonly separated from one another by swamp lands.

RELATIONS TO SURROUNDING ROCKS.

The relations of the Kitchi schists to the altered tuffs of the Mona schists have already been given. The relations of the Kitchi schist to the granite on the west are observable north of the west end of a pond in the SW. ¼, sec. 26, T. 48 N., R. 28 W. In passing from the schist to the granite, dikes of granite first appear in the schist; then the

[1]The Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan, by G. H. Williams. Bull. U. S. Geol. Surv. No. 62, p. 151, 1890.



PEBBLES FROM A CONGLOMERATE BAND OF KITCHI SCHIST.

granite gradually becomes predominant, schist layers being interlaminated with the granite dikes or anastomosing with the granite in an irregular manner. Going on toward the granite, the schist is found as angular blocks in it, and finally the solid granite appears, free from schist. The granite is therefore clearly intrusive within the schist. This granite near the contact with the schist is finer grained than the central mass. The sedimentary rocks north and south of the greenstone-conglomerates repose unconformably upon the latter.

VARIETIES, PETROGRAPHICAL CHARACTER, AND ORIGIN.

Macroscopically there are different phases of the rocks embraced in the Kitchi formation. The coarser, more conglomeratic phases resemble schistose sedimentary conglomerates, the pebbles of which are from a fine-grained, purplish-green rock in a matrix of the green schist. The nonconglomeratic beds are like the matrix of the conglomeratic ones, except that there are scattered through the rock small, light-colored grains of feldspar. These are often drawn out into lenses, or even into thin, sheet-like layers, running parallel to the planes of schistosity, when the rock presents somewhat of a gneissic aspect. In these rocks sharp-edged fragments of plagioclase may not infrequently be detected in the midst of a fine, satiny groundmass of chlorite plates and calcite grains, entirely different in character from the matrix of any schistose sedimentary rock met with in the district. The rocks are evidently basic tuffs.

Another variety of the schistose tuff occurs most commonly near the edges of the area, especially at the contacts with the Marquette beds. In the field notes the rock was called a sericite-schist. It is a pink to white, platy and schistose rock, with a very pronounced soapy feel. On surfaces of the hand specimen that are at right angles to the schistosity sharp particles of different minerals are to be seen, but on the surfaces parallel to the foliation the rock appears to be a typical sericite-schist or talcose schist.

The conglomeratic green schists are so much decomposed that it is difficult to learn from their thin sections much more concerning their original character than can be learned from their study in the field.

The pebble-like masses scattered through the schists are fragments of a purplish-pink, fine-grained rock, speckled with tiny green dots of chlorite and red or white ones of altered plagioclase. Enough of the feldspar remains to exhibit traces of twinning bars, although most of it has been replaced by sericite, calcite, and quartz. These plagioclases were originally well-outlined crystals. They lie in a groundmass composed of small feldspar laths, grains of epidote, and a weakly polarizing felsitic substance that is probably a devitrified glass. The rock of which these pebbles were a part was probably a porphyrite. Nothing exactly like it has yet been found in ledges.

The schistose groundmass in which the pebbles are imbedded consists of sharply angular fragments and complete crystals of altered plagioclase in a matrix composed of much chlorite and sericite, small fragments and crystals of plagioclase, always some calcite, and a fine-grained mosaic of secondary quartz. To these is sometimes added epidote in grains and plates. It is noteworthy that in these rocks chlorite has replaced the original iron-bearing silicate, while in the tuffs of the Mona schists to the east these silicates are now represented by hornblende. Whether this difference in composition is due to differences in the nature of the alteration processes to which the different rocks have been subjected, or to the fact that those of the greenstone-conglomerate area have suffered the effects of weathering to a greater extent than the schists, is not certain. It seems most probable, however, that both causes are responsible for the differences. The larger feldspar pieces in the groundmass have been referred to as crystals and fragments of crystals. In most cases they are unquestionably fragments. In many instances the pieces lying close together are dissevered portions of the same crystal, fractured across at right angles to the planes of schistosity in the rock. The fragments thus formed have been moved apart in the planes of foliation. The fracturing and the movements of the fragments are believed to be an effect of shearing, which is shown also in the rock's foliation. Many fragments are ragged in outline. They do not correspond with other fragments in their vicinity, nor have they the straight-egded contours of the fractured crystals. These are like the fragments in modern tuffs. They are in all probability pieces of crystals blown from volcanic vents.

The chlorite in the groundmass is in small prisms and needles, arranged usually in approximately parallel directions, forming narrow bands, which may be merely lines in some places and in others may expand into comparatively large lenticular areas. Chlorite occurs, also, in oval and irregular areas formed by the aggregation of its plates, intermingled with grains of epidote, of calcite, and of great numbers of rutile crystals that are usually included within the chlorite. As Williams has suggested, these areas may represent the basic fragments of the tuffs that have been altered beyond recognition. The sericite is as abundant as the chlorite in some specimens, while in others it is present in small quantity only. It appears as colorless or light-green flakes that lie scattered among the other constituents, especially between the chlorite prisms, and as tiny spicules that penetrate the grains of the mosaic matrix. Of the calcite, nothing need be said, except that it occurs as nests or as grains between the other minerals. In some of the more compact tuffs a second carbonate is sometimes met with in the form of small rhombohedra. The substance is more opaque than the calcite, and is of a yellow or yellowish-brown color. It is probably ankerite or ferruginous dolomite.

The matrix in which all the components of the groundmass lie resembles very closely the silicified background of many apo-rhyolites. Under very high powers of the microscope it is seen to be made up of intricately interlocking, colorless grains. Their aggregate polarizes like a fine-grained quartz mosaic. No twinning bars were seen in any of the grains examined, but frequently they exhibit an undulatory extinction. This groundmass is therefore regarded as quartzose. Some of this quartz may have been derived from the original constituents of the tuffs by alteration, but most of it, in all probability, has been introduced from without. The rocks have evidently been silicified, for we find ledges cut through and through by quartz veins, and in the microscopic section these veins can be followed as they break up into smaller and smaller ones, until their ramifications are finally lost in the mosaic above mentioned.

The rocks just described are evidently fragmental deposits. Their composition, however, is so different from that of water-made sediments, that we must ascribe some other origin to them. The banding of certain of the conglomerates and the alternation of layers in some of the finer-grained rocks would indicate that there had been a partial sorting of the fragments, but the nature of the fragments themselves and the composition of the matrix in which they lie would seem to preclude the notion that the materials were furnished by the wasting of preexisting rocks. In a few specimens an occasional large, rounded grain of quartz is discovered in the midst of the larger components, and in the mosaic a number of rounded and enlarged grains of the same mineral may be detected; but by far the greater portion of these rocks is exactly like the rocks in which no quartz grains have been seen.

The sericite-schists—most abundantly developed on the south side of the Kitchi area, in contact with the Marquette beds, but occurring also elsewhere interbedded with the schists—in thin section are essentially similar to the green schistose rocks interbedded with the conglomerates. They differ principally in containing sericite, rather than chlorite, as their principal micaceous component. Many of these light-colored schists are composed almost exclusively of sericite and quartz, but most of them contain chlorite also. By increase in the proportion of chlorite in them, they pass gradually into the green tuffs.

The composition of the green schist (I) and of the sericite-schist (II) is given below. The first is composed largely of plagioclase, chlorite, and quartz; the second consists principally of sericite and quartz.

	I.[1]	II.[2]
SiO_2	61.35	70.76
TiO_2	.26	.33
Al_2O_3	16.45	14.83
Fe_2O_3	.94	1.46
FeO	4.20	3.09
CaO	3.46	.36
MgO	3.12	1.99
K_2O	1.05	3.50
Na_2O	5.24	.47
P_2O_5	.18	.26
CO_2	1.98	....
H_2O at 100°	.10	.09
H_2O above 100°	2.51	2.70
Total	100.84	99.84

[1]Green schistose rocks speckled with red-weathering feldspars. No. 22062. From near center of sec. 34, T. 48 N., R. 27 W.

[2]Light grayish-green sericitic schist. No. 22085. From about 200 paces S. of NW. corner of same section. This particular sericite-schist did not come from the southern edge of the area, but was taken from a band interbedded with well-characterized conglomerates, about one-fourth mile from the edge.

From their composition and structure it is evident that the schist described as associated with the greenstone-conglomerates, as well as these latter rocks themselves, are tuffaceous deposits that have been rendered schistose by pressure, and which have suffered dynamic metamorphism and weathering until their original composition has been entirely changed. The darker-colored schists have now the characters of "schalsteins;" the lighter-colored ones are sericite-schists. The former were originally basic tuffs, and the latter in all probability acid ones interstratified with the former, which were in much the greater abundance. The pebbles occurring in the conglomerates are all of exactly the same character, and their nature is very similar to that of the schistose matrix in which they are embedded, except, of course, that they lack the schistosity of the latter. They must be looked upon as volcanic bombs or as large fragments of the lavas whose ashes produced the matrix, which fragments have become rounded by the shearing that caused the foliation of the finer particles.

Since the green schists are surface materials, they must have been deposited upon some previously existing basement. This basement has not yet been identified. It can not be the gneissoid granite, for the latter is intrusive in the former.

With the various schistose tuffs of the area there are often interstratified narrow bands of epidiorite and other schistose diabases, which are the remains of lava-flows that were interbedded between the ash deposits at the time of the eruption that gave birth to both.

THE GNEISSOID GRANITES.

The granites and gneisses of the Northern Complex are closely related genetically. Both are coarse-grained, both vary in color from dark greenish-gray to bright red, both are usually granular, and occasionally porphyritic, with large, red phenocrysts lying in a coarse, red groundmass, and both have suffered more or less severely the effects of pressure. The gneisses differ from the granites only in the perfection of the foliation that has been imparted to them, and in the amount of dynamo-clastic material discoverable in them. The gneisses are indisputably foliated phases of the granite, which is always more or less schistose. Since the origin of these gneisses is known, it seems better to designate them by a name that will indicate their origin, leaving the term gneiss to cover those foliated rocks of the composition of granite whose origin is problematic.

DISTRIBUTION AND TOPOGRAPHY.

The gneissoid granites occupy two distinct areas in the Northern Complex. Although widely separated, the rocks occurring within them may be treated together, since they are alike both in macroscopic and in microscopic characters, and so far as can be learned they bear exactly the same relations to the surrounding sedimentaries and crystallines. The easternmost of the two areas is north of the Mona schists, and beyond the limits of the map. It extends northward nearly to the lake shore, and westward until it connects with the eastern limb of the second area, which is within the limits of our work. This second area begins at the western side of the Kitchi formation and extends westward beyond the district treated in this paper. On the south it is bordered by the Algonkian beds of the Marquette area, and on the north by the slates and quartzites of the Arvon district.

The granites, whether massive or gneissoid, form knobs which, like those of the greenstone-schists, are in some cases isolated and in others grouped to form rugged hills. The surface features of the area underlain by the granite are thus essentially similar to those of the green-schist areas.

RELATIONS TO SURROUNDING ROCKS.

The relations of the granites to the green schists with which they are in contact have already been mentioned. The granites and their accompanying gneisses are younger than the schists. They are, however, older than the fragmental beds above the schists, since none of their dikes intersect these, even when the igneous rock is in contact with the sedimentary ones. On the other hand, bowlders of the former are often found in the lower beds of the latter. Occasionally a small mica-schist ledge is met with in the midst of granite ledges; and these may represent a series of rocks underlying the green schists, and older than they, but no evidence either in favor of this view or in opposition to it has thus far been collected.

VARIETIES, PETROGRAPHICAL CHARACTER, AND ORIGIN.

As has already been stated, the more massive and more schistose phases of the granites—the gneissoid granites and the granitoid gneisses—are believed to be portions of the same rock mass, and therefore they are discussed together. Further investigation may show that some of the gneisses are older than some of the granites, and that the older rocks form a portion of the basement upon which the later greenstone-schists were deposited, but up to this time no discrimination between the massive and the schistose granites has been attempted.

The rocks vary in color from grayish green to bright red, the color of the former varieties being due to the abundance of chlorite in them. Their feldspar is rarely white. It is usually of a light-red or pink color. When bright red it gives the entire rock of which it is a part a red tint, which varies in brilliancy according to the quantity of feldspar in it. In a few instances bright-red orthoclases are scattered through a groundmass of gray granite, but this variety is usually found only near the contacts of the rock with the greenstones or in its apophyses that intruded the latter.

Microscopically the granites and their gneissoid varieties are seen to be composed of clouded orthoclase and plagioclase (the former mineral predominating), quartz, and brownish-green biotite, or its decomposition products. Occasionally chlorite is present, which appears from its shape to have been derived from hornblende, but no undoubted amphiboles have been detected in the northern granites. They are all biotite-granites or granitites. The accessories are small crystals of sphene, some leucoxene and magnetite, and an occasional zircon.

The original constituents of the granites require no special description. The feldspars are altered to kaolin, sericite, and calcite. These products, together with a red earthy dust, probably an ocher, are so thickly clustered that they very nearly obscure the twinning bars of the plagioclase, and cause it to be confounded with the orthoclase. The biotite was originally a brownish-green variety. At present but few remnants of the mineral remain. It has been changed to single plates and aggregates of flakes of a pale to bright green chlorite, polarizing with blue tints. This chlorite is sometimes intergrown with muscovite, but only in those cases where the latter is evidently a product of dynamic action. No specimen of the granites examined is free from pressure effects. In every slide placed under the microscope more or less distinct traces of dynamic metamorphism are recognized.

The quartz appears in two forms, either as irregular grains of the usual character of granitic quartz, or as little masses filling triangular areas between the other components, and sending arm-like projections into them. Some of it is in all probability original; much of it is unquestionably secondary. All of it is marked by the undulous extinction, and a part of it is completely shattered.

The feldspar is granulated peripherally. The fragments thus derived are mingled with chlorite flakes, epidote grains, and occasionally a little muscovite, and the whole is cemented by newly-formed feldspars, among the most prominent of which is microcline.

Not only is microcline present in this fragmental aggregate, but it occurs also as colorless rims around the cloudy orthoclase, and also very often replacing the material of the latter. A large, cloudy orthoclase may very often be found completely saturated with clear, colorless microcline substance. There is no sharp line of contact between the two feldspars, but they seem to grade into each other. As the microcline replaces the orthoclase it absorbs the alteration products of this mineral, the resulting new feldspar thus being free from inclusions, while the original feldspar is full of them. A third form in which the microcline very frequently appears is as the filling of the angular spaces between the components of the fragmental aggregate. It was evidently formed in large quantity after the crushing of the original minerals of the granite, and inserted itself into every crevice and space between them, in some cases even forming tiny veins cutting across quartz grains.

Fresh plagioclase is also a common new product in some sections. It occurs as grains among the crushed materials, and sometimes it surrounds cloudy feldspar as a clear, colorless zone. Its twinning bars are usually much bent, and nearly always they present a few or more of the usual features due to pressure.

The epidote grains in the mosaic need no description. They are very light in color, and therefore show no pleochroism. The muscovite that is sometimes associated with the biotite or chlorite is found with these minerals only when they are in the aggregate, and then only when in contact with orthoclase, a large mass of chlorite often being separated from the orthoclase by a rim of muscovite. This mineral is also present in long, stringer-like aggregates of flakes, sometimes penetrating the mosaic, but usually separating it from the unfractured original granitic components.

The mosaic of fractured minerals and new products is always more or less schistose. This structure is produced by the lengthening of the fragments in a common direction, and by the development of the chlorite and muscovite in large, narrow flakes and groupings of flakes. The mosaic is also traversed by bands, in which the fragments are very much smaller than elsewhere, as though the rock had slipped along certain planes and had ground into powder the neighboring fragments. These bands run in the same direction as do the stringers of chlorite and muscovite, and so help to impress schistosity on the mosaic. They are microscopic shear zones.

The structure of all these granites is that described by Tornebohm under the name "mortar-structure." Williams has already referred to it as characteristic of the granites of this region, and has cited its existence as evidence that the rocks in which it is found have been subjected to severe dynamo-metamorphism.

The gneissoid granites differ from the more massive phases of the rocks simply in the possession of more marked foliation. The mortar-structure is most beautifully exhibited in all the sections. The larger remnants of the crushed original components are embedded in the mosaic, which surrounds them as the crystalline matrix surrounds the eyes of an "augen-gneiss," the combination of fragments and mosaic producing lenticular areas, separated from other like areas by narrow bands of very fine mosaic.

It is not uncommon to see in a slide of the gneissoid granite a grain of orthoclase or of plagioclase broken into three or four pieces and the pieces separated from one another by distances of a quarter millimeter. The fissures between the fragments are filled with an aggregate of crystallized quartz and microcline, or with a portion of the fragmental mosaic.

The quartz grains have suffered crushing, but their parts have not been separated. Quartz areas now consist of nuclei peripherally granulated, or of many portions differently orientated, but the whole forming a lenticule. Each component of the lenticule exhibits undulous extinction.

All of the older granites of the Northern Complex present features like those discussed, except a very few whose relations to the more common granite has not been determined. In the SW. ¼, sec. 29, T. 48 N., R. 28 W., for instance, is a crushed muscovite-granite. This may be a dike in the granite, like the aplitic dikes that will be mentioned later.

As to the origin of the granites and their gneissoid phases, there can be little question. The rocks appear like eruptives in the field. The clastic grains discoverable in their thin sections are evidently of dynamic origin. All are sharply angular. None have the rounded outlines of waterworn grains. The structure of the rocks is very similar to that of schists elsewhere that have been shown to be sheared eruptives; hence there is no reason to believe the granites and gneisses of the Northern Complex to be anything but squeezed igneous rocks. It is impossible to trace them back to an earlier source than a molten magma; therefore, whatever may have been the origin of this magma, we are justified in calling the rocks igneous. There is no evidence of any kind to support the belief that the gneissoid granites in this portion of the Marquette region were ever water-deposited sediments that have been crystallized by metamorphic processes or by pressure.

THE HORNBLENDE-SYENITE.

The syenite, so far as has been observed, with its gneissoid phases, is found only in a narrow belt, from a quarter of a mile to a mile in width, lying between the green schists on the south and the fragmental beds of the Silver Lake Algonkian area on the north. The belt is about 5 miles long, and it lies almost entirely within T. 48 N., R. 26 W. The syenite is so like the granite in its nature that but little remains to be said concerning it, except to describe its microscopical features.

TOPOGRAPHY AND RELATIONS TO OTHER ROCKS.

The topography of the area occupied by it is exactly like that of the granitic country. The relations of the syenite to the surrounding rocks are also like those of the granite. Its apophyses cut the green schists, and its main mass is unconformably beneath the Algonkian sediments. As to the relations existing between the syenite and the granite, nothing is yet known positively. A very few ledges of the gneissoid granite have been found within the limits of the syenite area, and these, when examined with reference to the latter rock, appear to have been intruded by it. The appearances, however, are not decided enough to warrant an expression of opinion as to their meaning.

PETROGRAPHICAL CHARACTER.

The primary constituents of the syenite are orthoclase, plagioclase, hornblende, sphene, magnetite, and, very rarely, biotite. Its secondary components are plagioclase, microcline, chlorite, quartz, muscovite, and leucoxene.

The primary feldspars are clouded with alteration products, while the secondary ones are clear. The hornblende is in dark brownish-green crystals that are idiomorphic in the prismatic zone, but badly terminated at their extremities. It is nearly always more or less completely altered to chlorite. The sphene is also rarely fresh. It is usually changed into a cloudy, light-colored substance that looks yellow in reflected light, and in general appearance resembles leucoxene. It often forms complete pseudomorphs of the sphene. The secondary feldspars bear the same relations to the original ones as do the same minerals in the granites.

The quartz, which is always present to some extent, but never so abundantly as in the granites, occurs sometimes as small grains with an undulous extinction, sometimes as larger ones broken up into an aggregate of differently orientated particles. Most of the mineral, however, is in the angular spaces between the feldspars or in the cracks traversing the older constituents. A small portion of the quartz may be original, but the greater portion is thought to be secondary.

The structure of the gneissoid syenites is identical with that of the granites, so it needs no discussion in this place. The syenite, as well as the granite, is an igneous rock that has suffered dynamic metamorphism. The latter is a quartz-biotite-orthoclase rock, and the syenite an aggregate of hornblende and orthoclase. Even were the two rocks not distinguished by the abundance of quartz in the one and its rarity in the other, they would be distinguished by the presence of the biotite in the granite and of the hornblende in the syenite.

THE DIKE ROCKS.

The granites, the basic schists, and the acid schists of the Northern Complex are cut by numerous dikes of basic and of acid material, of which the former are much the more common.

THE BASIC DIKES.

The basic dikes cut the gneissoid granite and the schists indiscriminately, though they may be more abundant in the greenstone-schist areas. They vary in width from an inch or two to 75 feet or more, and in length they sometimes have been followed 2 or 3 miles.

These dikes have been so well described by Williams[1] that there is little left to be said in this place concerning them. Diabases, epidiorites, and diorites were distinguished by Williams. The diabases are of the usual types. The epidiorites are thought to be uralitized and epidotized diabases, since their structure is plainly ophitic, the feldspar occurring in lath-shaped crystals, and the amphibole forming fibrous wedge-shaped areas between the plagioclase laths. The diorites differ from the epidiorites mainly in structure and in the compact nature of its hornblendic component. The amphibole in the diorites is compact and idiomorphic, and hence it was considered by Williams as original. In some slides of these rocks, however, are cross-sections of a compact, brownish-green hornblende that is perfectly idiomorphic, while at the same time nests of light-colored augite may be seen included within its mass. If this hornblende is secondary, as it seems to be, then it is probable that many of the supposed diorites of the region are altered diabases, just as are the epidiorites, which contain fibrous amphibole.

The freshest diabases, those still containing large quantities of pyroxene, are quite massive, even when the rocks through which they cut are completely schistose. These, then, must have been intruded in the schists after the latter had become foliated, and must be younger than the diorites and epidiorites, all of which are schistose. Mineralogically the diabases present no special features. Some of them are now olivinitic, while others contain pseudomorphs of chlorite and limonite after olivine.

In structure, all the diabases present the same features. They are all ophitic, with a few exceptions, in which a porphyritic development of the pyroxene and feldspar is noticed. In some of the dike masses these two minerals are in comparatively large phenocrysts, embedded in a plexus of small laths of plagioclase and tiny, rounded grains of augite.

A diabase-porphyrite differs from the type just mentioned in the absence of pyroxene phenocrysts and in the presence of magnetite in large quantities. The latter mineral is found not only in the little grains between the constituents of the groundmass, but also in large, irregular masses scattered through the rock and in skeleton crystals resembling the microlites in basic glasses (fig. 10). These microlitic growths form long, slender, straight rods cutting through the grains of the groundmass and through phenocrysts indiscriminately.

[1] The Greenstone-schist Areas of the Menominee and Marquette Regions of Michigan, by G. H. Williams. Bull. U. S. Geol. Surv. No. 62, pp. 138-146, 168-175, 180-184, 189-190, 1890.

Most of the basic dikes of the district are epidiorites, and these are always more or less schistose. The phases vary from one another mainly in the form of their hornblendic constituent and in the freshness of their plagioclase. In some of these rocks the augite has been pseudomorphosed to green hornblende; in others this mineral is in isolated or in grouped acicular crystals, the ends of which often extend far out into the altered plagioclase surrounding the areas originally occupied by ophitic augite. In the least-altered epidiorites the plagioclase is fresh, and in these varieties augite cores often remain as unclei within the amphibole areas. As alteration progresses the plagioclase becomes more and more clouded by alteration products, until finally it becomes an aggregate of epidote, chlorite, amphibole, and calcite. Fine examples of leucoxene are seen in many specimens. The mineral occurs as little, cloudy masses around titanic iron-grains, and also as pseudomorphs of the latter mineral, replacing it completely in some cases. In other cases bars of the opaque iron oxide form a network in whose meshes are the white, opaque grains of leucoxene. The leucoxene passes into a dense yellowish-brown mass, with the pleochroism of sphene. The character of the alteration that changed diabases into epidiorites, coupled with the existence of schistosity in the latter rocks, is thought to be sufficient reason for ascribing the origin of the epidiorites to dynamo-metamorphism of diabases.

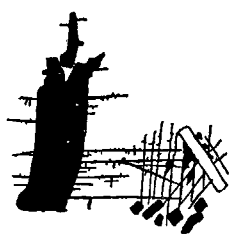


FIG. 10.—Magnetite in fine-grained diabase or basalt.

The "diorites" of the Northern Complex are probably altered diabases, in which the new hornblende has assumed a compact rather than a fibrous form. The hornblende crystals are always frayed out at their ends, but in cross-section they are compact and idiomorphic. The original feldspar has been entirely replaced by a transparent plagioclase that is cut through and through by slender needles of hornblende, at whose ends terminal planes may often be detected. Under crossed nicols large areas of the plagioclase break up into many small ones, interlocking with one another by sutures which follow the most intricate courses. This feldspathic mass differs so greatly from that of the epidiorites in appearance, in freshness, and in its structure, that we must regard it as essentially different in its origin. The feldspar of the epidiorites is a decomposed plagioclase, while that of the diorites is apparently a recrystallized one. The diorite as it now exists is not an original rock. It has been formed from some preexisting eruptive, but whether from an original diorite or a diabase is not certainly known.

The final products of weathering of all the basic rocks described as occurring in dikes are chlorite, epidote, kaolin, calcite, and quartz. A number of dike masses are known in the Northern Complex that consist principally of these minerals. Most of them present the ophitic texture of diabases, while in others the granitic texture of diorites and gabbros is recognizable. All are highly schistose. Chlorite is by far the most abundant component, and the rocks therefore, are practically chlorite schists. All that have been studied are unquestionably squeezed eruptives.

THE ACID DIKES.

The acid dikes cutting the rocks of the Northern Complex are not so numerous as are the basic ones, but their variety is greater. They include coarse granites and granite-porphyries, fine-grained granites, aplites, quartz-porphyries, and the aplitic form of quartz-diorite known as malachite.

No descriptions of the coarse granites and granite-porphyries are necessary. They are apophyses of the great granite masses north of the schists, and do not differ in character from these. They are of the same age as the gneissoid granites, and hence are older than the various aplitic and diabasic dikes that intrude the granite.

The remaining acid dikes are usually of inconsiderable size when compared with the great basic dikes that traverse the schists and granites. They are also of various ages. Some are foliated and others massive. The former were intruded before the last effects of pressure had been impressed upon the schists, and the latter long after the schists were made, for they intersect even some of the massive diabase dikes. The color of the dikes varies from pinkish gray, through pink, to a bright red. Their material is always compact, and except when here and there it is microlitic it is also very fine-grained. Many of these dikes are fine-grained granites, with no peculiar features. Their feldspar is usually red or pink, and their principal bisilicate is a chloritized biotite. Others partake more of the aplitic character. Their feldspathic component possesses more or less perfectly quadrangular cross-sections, and their quartzes circular ones. Both the granites and the aplites are altered.

A few dikes of a fine-grained, dark-gray rock are of interest, since they represent the aplitic form of mica-diorite, named malachite by Osann.[1] The best specimen of this rock came from a dike 600 paces north of the southeast corner of sec. 18, T. 48 N., R. 28 W. It is an aggregate of plagioclase, orthoclase, quartz, and biotite. All the components are much altered. The biotite is chloritized, the orthoclase kaolinized, and the plagioclase saussuritized. Plagioclase and quartz compose the greater portion of the rock. The former is in little grains with irregular outlines that exhibit a tendency to become quadrangular, and the latter in grains between the plagioclases. In structure the rock is panidiomorphic.

The quartz-porphyry dikes have already been studied by Williams. The rocks are light colored. They sometimes still have their original

[1] Mitth. Gross. Bad. geol. Landesanstalt, II, p. 380. Cf. also Microscopic Study of Some Michigan Rocks, by H. B. Patton. Rep. State Board Geol. Surv. Mich. 1893, pp. 184–186.

characters sufficiently well preserved to exhibit the porphyritic structure. In other and more numerous instances the rocks are schists. Their porphyritic orthoclases are broken and their fragments displaced, their porphyritic quartzes are granulated, either entirely or only peripherally, while the quartz-orthoclase mosaic that originally constituted their groundmass is now a schistose aggregate of quartz and sericite. In not a few of the porphyries plagioclase accompanies the orthoclase as phenocrysts, and chlorite, filled with tiny brown rutile crystals, is distributed through the groundmass as shreds, apparently replacing an original biotite.

THE PERIDOTITE.

The serpentine and peridotite form high, ragged bluffs that are noticeable for their dark color and jagged contours. One of these bluffs forms Presque Isle, on the shore of Lake Superior, about 2½ miles north of Marquette. The principal occurrences of the two rocks are, however, northwest of Ishpeming, in the area of the Kitchi formation.

THE PRESQUE ISLE AREA.

The rocks of the Presque Isle area are so well known, thanks to Dr. Wadsworth,[1] that we need give them little attention. They were all originally peridotites, but they have undergone alterations due to weathering until they are now largely serpentines and dolomites. Among the freshest phases of the rock lherzolites, picrites, and wehrlites have been distinguished.[2]

The peridotite and its altered varieties form an immense knob underlying Potsdam sandstone. Since the conglomeratic lower layers of the fragmental rock contain pebbles of the peridotite, and since a diabase dike in the latter is overlain by horizontal layers of the sandstone, it is concluded that the peridotite is older than the sandstone. Its age with respect to the Algonkian fragmentals is not yet known. It is probably older than the green schists, for it is similar in all essential features to the peridotite of the Opin area, and this intrudes the Kitchi schists.

Analyses of the serpentine of Presque Isle were made by Whitney[3]

[1] Lithological Studies, by M. E. Wadsworth, 1884, p. 136.

[2] Report of the State Geologist for 1890-91, by M. E. Wadsworth. Rep. State Board Geol. Surv. Mich., 1893, pp, 134-138.

[3] Notice of New Localities and Interesting Varieties of Minerals in the Lake Superior Region, by J. D. Whitney. Am. Jour. Sci., 1859, Vol. XXVIII, p. 18.

in 1859. They are of those portions of the rock that were decomposed by fused sodium carbonate, and are evidently not complete.

	I.	II.	III.
SiO_2	36.95	37.25	....
Fe_2O_3	16.50	6.75	12.90
FeO	....	14.14	19 52
MgO	33.07	28.67	14.83
Na_2O	.97	1.16	....
H_2O	10.40	10.89	....
Total	....	98.86	....

THE OPIN AREA.

Surrounding and southwest of Opin Lake, in T. 48 N., R. 27 W., the rocks that have been classed as peridotites and serpentines embrace also dolomitic serpentines and almost pure dolomites. Intermediate phases between these four types are very numerous, so that there is no difficulty in tracing almost pure peridotites through serpentinous varieties into pure serpentines, and these into dolomites.

The Opin area includes a number of detached exposures, the larger from 1 to 3 miles long, surrounded by green schists and greenstone-conglomerates. The combined areas trend diagonally across the various belts of schist. Each area is composed of from few to many boss-like knobs. The peridotite is never schistose, except along shear-planes. Both acid and basic dikes intersect the schists, whereas all dikes, except the very freshest of the diabases, are absent from the peridotite. These facts would indicate that the peridotite is an irruptive of later age than the schists. Dr. Wadsworth has recently described an eruptive contact of the serpentine with the schists, and a dike of the peridotite intruding diabase, diorite, and felsite. There can be no question, then, that the peridotite and its derivatives are younger than the Deer Lake Kitchi schists. From the relation of the various dike masses to it, it would seem to be the latest intrusion in this area, with the exception of the fresh diabases, whose irruption continued until the close of Upper Marquette time.

The freshest peridotite in this area is near the center of the E. ½ sec. 27, T. 48 N., R. 27 W. The rock is composed of fairly well-preserved diallage, olivine, magnetite, and plagioclase. The olivine is in well-defined crystals, embedded in large plates of pale pink, almost colorless diallage, that nearly fill the section. In the small interspaces between them occurs the plagioclase, as a weakly refracting, altered, white or colorless substance occupying the same relation with respect to the diallage and olivine as glass does to the crystals in a hypocrystalline rock. The olivine and diallage are both serpentinized in part, and the diallage is in places uralitized and chloritized, especially near its contact with the plagioclase. The small amount of magnetite present is found amongst these decomposition products, as are also a few flakes of biotite. Calcite fills cracks in the other components and the spaces left between them. The rock has the composition, but not the structure, of wehrlite. Its analysis, made by Dr. W. F. Hillebrand in the Survey laboratory, is as follows:

SiO_2	39.37	BaO	Trace.
TiO_2	.66	MgO	26.53
Al_2O_3	4.47	K_2O	.26
Cr_2O_3	.68	Na_2O	.50
Fe_2O_3	4.96	H_2O below 110°	.87
FeO	9.13	H_2O above 110°	7.08
MnO	.12	CO_2	1.23
NiO	.21	P_2O_5	.17
CaO	3.70		
SrO	Trace.	Total	99.94

From this analysis it is seen that the rock is more altered than would be judged from the investigation of its single thin section at hand. It is also noticeable that, like other peridotites, it contains small percentages of several rare metals, as titanium, chromium, manganese, and nickel, besides traces of strontium and barium.

From most of the sections of specimens taken from the Opin peridotite, the olivine and diallage or other pyroxene have entirely disappeared and serpentine or dolomite has taken their places. In many of these the original structure of the peridotite may still be detected, while in others nothing can be seen but fibrous masses of serpentine, irregular areas and tiny veins of dolomite, and some magnetite and earthy products. When the serpentine predominates, the rocks are well-characterized calcareous serpentines; when the dolomite prevails they become almost pure dolomites. These latter rocks are not so abundant in quantity as the serpentines are. They are found usually as veins cutting the latter rocks, and as indefinitely defined bands bordering cracks and joint planes in them.

SECTION II. THE SOUTHERN COMPLEX.

The rocks of the Southern Complex are separated, in mapping, into two distinct areas, the Palmer gneiss and the granitic area. The first consists mainly of schistose rocks, but includes granite; the second is composed mainly of granitic rocks, but includes schists. The Palmer gneiss constitutes a narrow belt south of the Algonkian in ranges 26 and 27, while all of the remaining rocks are placed in the granitic area. The relations between the rocks of the Southern Complex and those of the Algonkian are referred to in connection with the last. There is a marked unconformity between the two.

The topography of the southern granite area differs but little from that of the northern. In the eastern part of the belt the drift is thicker than in the western part, so that knobs of granite protrude above sand plains. These knobs are in isolated ledges, or are aggregated to form hillocks with several peaks, separated from one another by little defiles. The hillocks themselves are separated by drift deposits, so that the belt in its eastern portion is in reality composed of distinct areas of granite.

Between the north and south center line of range 27 west and the west line of range 28 west, the country becomes swampy and ledges are rare. When they occur it is as small, low outcrops in the midst of the swamps. Farther west hills and swamps alternate, and the surface has the usual aspect of pre-Algonkian topography.

THE GRANITIC AREA.

The various rock types occurring in the granitic area are so involved with one another that it is often difficult to determine which is the predominant form in any given locality. In general, granites prevail to the east. For a distance of 10 miles west of the shore of Lake Superior granites are about the only rocks met with. Farther west there are associated with them gneisses, mica-schists, hornblende-schists, greenstone-schists, and occasionally white sericitic schists, many of which are sheared granites. The schists and the granites, like the rocks of the Northern Complex, are cut by basic and acid dikes, of which the former are by far the most important.

So intricate are the relations of the schists with one another that it is hard to make out the order in their ages, but the mica-schists and hornblende-schists appear to be older than the greenstone-schists, and the gneisses to be of the same age as the granite.

The schistose rocks associated with the granites strike approximately east and west, and have high dips. They comprise a hornblendic and a micaceous group. In the first are greenstone-schists, feldspathic hornblende-schists, and hornblende-schists. In the second are the mica-schists and feldspathic mica-schists. The hornblende-schists are frequently micaceous, and the mica-schists are frequently hornblendic. The greenstone-schists are in general very similar to those of the Northern Complex.

THE GRANITE.

The granite is clearly eruptive. Its contacts with the schists are eruptive contacts, and its apophyses often intrude the schistose rocks to great distances. In places it is quite massive and has all the characteristics of a plutonic rock, while in other places it is strongly schistose, forming gneissoid phases. The relation of the gneissoid and the more massive granites is so intimate that even without the microscopical evidence there would be little doubt that the two phases are varieties of the same rock. Petrographically the granites of the Southern Complex are very similar to those of the Northern Complex. The differences are those of minute detail, and they will not be given in this paper.

THE HORNBLENDE-SCHISTS.

The hornblende-schists and feldspathic hornblende-schists are lustrous, highly foliated rocks, with a compact, crystalline texture and a fresh-looking appearance. Occasionally bandings of light and dark shades may be observed in specimens, but usually the rocks are uniformly black in color. In thin section the hornblende-schists are different from anything found in the Northern Complex within a short distance from its boundary with the Algonkian, although similar rocks may be present in abundance elsewhere within the area. The greater proportion of them contain plagioclase in addition to the quartz and green hornblende. The feldspar is in clear grains, crossed by twinning bars, and is in most cases a basic feldspar. Both the plagioclase and the quartz grains interlock as though they had crystallized in their present position. Some of the schists contain but small quantities of the feldspar, while others consist almost exclusively of plagioclase and hornblende, the quartz being represented by but few grains in a section. Magnetite may be more abundant in these phases of the schists than in the quartz-hornblende aggregates, but it is not present in large quantity, even in these rocks. When present it is usually as inclusions in the amphibole. In many of the plagioclase-bearing schists there are also often discoverable grains of a decomposed feldspar that is probably an orthoclase. It bears the same relation to the other constituents as does the plagioclase, and is probably, like this component, an original crystallization in its present position. The feldspathic schists are like some of the freshest of the northern amphibole-schists derived from old tuffs. No conclusive evidence has yet been collected to show that the southern schists are modified tuffs, or even modified eruptives, although this seems to be the case. The feldspathic varieties are connected by micaceous phases with the micaceous hornblende-schists, and these are in all probability eruptive in origin. If this supposition be correct, the feldspathic hornblende-schists are also eruptives that have been changed from the massive to the schistose form through dynamic agency.

THE MICACEOUS SCHISTS.

The micaceous schists may be divided into true biotite-schists and those which are feldspathic. The rocks called biotite-schists are essentially aggregates of quartz and biotite, without any large admixture of feldspar. They vary in appearance from compact, gray, slightly foliated rocks to those that resemble light-gray and dark-gray bands of a friable sandstone. They are all so simple in composition that they need little description.

Quartz and brown biotite make up the major portion of the schists, but there are always in addition a few small grains of magnetite, zircon, and epidote, and often particles of plagioclase or of orthoclase. The quartz is clear and colorless. It frequently incloses small spicules of green biotite and green hornblende, but otherwise is free from inclusions. The biotite is in large flakes between the quartz grains, around which it extends, embracing often two or three in a single flake. The biotite is thus younger than the quartz. The magnetite, zircon, and epidote present no peculiar features. In the banded schists some of the layers are of the composition and structure described, while others are of the nature of the feldspathic mica-schists.

The feldspathic schists are nearly all graywacke-like in their macroscopic appearance. They are usually free from decomposition products of any kind. Most of them are composed of perfectly clear plagioclase, a little cloudy orthoclase, much brown biotite, and an occasional grain of quartz. Sometimes a few grains of epidote and of magnetite accompany the other components, but in no instance are they in large numbers.

The origin of these schists has not yet been ascertained. They have the appearance of original rocks, though they may be altered eruptives. Their plagioclastic constituent is well crystallized and fresh, and is the oldest component present, and still it may have originated, like the fresh albite in the mosaic of many of the northern greenstones, by the alteration of the material of a basic eruptive. When the proportion of orthoclase in the schists increases, the evidence of a secondary origin for the present constituents grows stronger. Large Carlsbad twins of orthoclase and grains of plagioclase—both minerals altered and filled with shreds of kaolin, crystals of magnetite, and spicules of hornblende—lie in a matrix composed of quartz, feldspar, biotite, and a little green hornblende. The biotite is the youngest of the components. It occurs between the other minerals, often surrounding them, and at the same time it is present within the feldspars as inclusions. It is more frequently in the orthoclase than in the plagioclase, and more commonly between the grains of the former mineral than between those of the latter. Moreover, some of the fresh feldspar appears to be a decomposition product of older plagioclase, just as some of the microcline of the northern granites is a product of the alteration of older feldspars. It thus appears that some, if not all, of the biotite and fresh plagioclase of these schists is secondary, and that originally the rocks possessed a different composition from what they do to-day.

THE PALMER GNEISS.

The formation is named Palmer gneiss because typical exposures are found west of Lake Palmer. The schists are light-gray, or dark-gray, or pinkish in color. They are fine-grained, sometimes apparently homogeneous like a chert, and at other times showing little eyes of quartz in a hydromicaceous matrix, like a devitrified and schistose quartz-porphyry. All varieties are highly foliated.

Under the microscope the gray varieties of the schists present a uniform structure, with very little mineralogical variation. They show undulatory extinguishing quartz grains, with irregular contours and granulated borders, lying in a matrix composed of sericite, muscovite, occasional particles of calcite, and sometimes small flakes and plates of biotite, besides remnants of feldspar. All the minerals of the matrix are in very tiny grains, and together they form a felted mass of nearly uniform composition. This felt of secondary minerals obscures completely, in most instances, all traces of the materials from which it was derived, except for the remains of feldspars that may be detected here and there between the fibers. The outlines of the original minerals, from which the secondary ones were formed, having in most cases disappeared, it is impossible to determine the original structure of the rocks and their nature. The quartz is crushed, as it is in the gneissoid granites. The grains are usually lenticular, and they always show an undulatory extinction. They are granulated around their edges, and especially at the ends of the lenticules, where mosaic areas of quartz grains have accumulated. Tails of the same mosaic stretch from these areas along the planes of foliation, winding in and out between the rock's components, and aiding in the production of its schistosity. Occasionally entire quartz grains are crushed, and an aggregate of small grains now occupies their places.

There are certain slides of the schists in which a fine-grained quartz mosaic forms triangular areas with curved sides, like the areas between the grains of a sandstone, and in a few other slides very narrow strings of the mosaic wind around and between rounded masses of the micaceous felt, as though the aggregate replaced an interstitial substance lying between the coarser grains of a fragmental rock.

The white and pink schists differ very slightly from the gray schists described above. Many of them are very fine grained, and these present the same features as does the matrix of the gray schists. The large quartz grains are absent, and the entire rock consists of the felt matrix.

Many of the rocks which in the field were supposed to be granites or gneiss are discovered, in thin section, to belong with the Palmer gneisses. A number of other rocks that are apparently gneisses in the field are found to have a fragmental appearance when their sections are placed under the microscope, but it is not possible to decide whether the fragments are water-worn grains or autoclastic grains produced by the crushing of a granite; the latter is apparently more probable.

THE DIKE ROCKS.

In the Southern Complex, as in the Northern Complex, the schists and granites are cut by well-characterized dikes and veins of eruptive material. The characters of the dikes in both areas are much alike. They comprise diabasic, epidioritic, and aplitic kinds. The basic dikes were evidently formed at different times, for some of them are schistose and are, clearly, altered diabases, while others are beautifully fresh and entirely massive. The latter must be much younger than the former.

They were perhaps intruded during Keweenawan time, for they are identical in composition and general character with the smaller dikes cutting Upper Marquette sediments, while at the same time none of them have been found penetrating the Cambrian. Among the materials of the fresher dikes may be mentioned ophitic diabases, olivine diabases, basalts, luster-mottled gabbro-like diabases, and uralitic diabases.

The older and usually larger dikes are epidioritic and uralitic schistose diabases, exactly like similar rocks in the Northern Complex, and practically identical with the material of the large, boss-like dike masses in the Huronian.

SECTION III. ISOLATED AREAS WITHIN THE ALGONKIAN.

In addition to the two areas of the Basement Complex which have been discussed, there are isolated patches of pre-Algonkian rocks lying entirely within the Algonkian area. Some of these areas perhaps represent islands within the Algonkian sea, while others are portions of the pre-Algonkian mainland that have been forced upward through the overlying rocks by the forces that folded and compressed the latter. They form the axes of anticlinal folds, and are naturally longer in the direction of the strike of the folds, and when the material of the nuclei is schistose the direction of the schistosity is usually parallel to the elongation of the areas. They are bordered by fragmental beds belonging with the lowermost formations comprised within the folds.

The rocks forming the greater portion of the isolated areas are gneissoid granites and schistose greenstones that differ in no essential respect from the corresponding rocks of the Northern or the Southern Complex. The greenstone-schists of the isolated area south of Marquette are identical with the Marquette schists. The granites consist of the same minerals as do the other granites of the Basement Complex, but they have become gneissic through pressure. Under the microscope their constituent minerals are seen to be shattered and crushed to such an extent that many sections look like those of fragmental rocks. The fragments, especially those of quartz, have been rounded by attrition, and the feldspar has been granulated so that the sections resemble those of an arkose containing large, water-worn quartz grains. As alteration progresses the feldspar changes to a mosaic of sericite, kaolin, and quartz, which often becomes so abundant as to obliterate the outlines of the feldspar fragments or to wholly destroy the grains. In this extreme phase of alteration the rocks present the appearance of sericite-schists, such as are so common in the belt of Palmer gneiss in the northern border of the Southern Complex. Since many of these sericite-schists occupy shear zones in the granites, there can be no question as to their origin.

CHAPTER II.

THE LOWER MARQUETTE SERIES.

The Lower Marquette series consists, from the base upward, of the following formations: The Mesnard quartzite, the Kona dolomite, the Wewe slate, the Ajibik quartzite, the Siamo slate, and the Negaunee formation. At the beginning of Lower Marquette time the transgression of the ocean was from the east and the north, and as a consequence the inferior formations of the Lower Marquette series appear only in the northeastern part of the district. South of Palmer and westward the lowest formation found is the Ajibik quartzite; that is, the three inferior formations of the Lower Marquette district were not here deposited, this part of the district then being above water.

SECTION I. THE MESNARD QUARTZITE.

The formation is given the name Mesnard quartzite because it composes the larger part of the mass of Mount Mesnard south of Marquette and because the predominant rock is quartzite.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The Mesnard quartzite makes up a continuous belt adjacent to the Archean on the south side of the series (see Pl. XIII), extending eastward from Lake Mary, sec. 9, T. 47 N., R. 25 W., to the sand plains west of Lake Superior. In secs. 1 and 2, T. 47 N., R. 25 W., the formation extends north to an island of Archean in secs. 2 and 3, and swinging both east and west of this island, it entirely surrounds it. Upon the northern side of the Lower Marquette series, the Mesnard formation extends continuously, south of the Archean, from Lake Superior to the west side of sec. 29, T. 47 N., R. 25 W. For several miles to the west of sec. 29 there are no exposures, but just east of Carp River a heavy belt of quartzite again appears next to the Archean, and runs westward as far as Teal Lake. The peculiar distribution of the formation is explained by its folding, which is considered below.

On account of the resistant character of the quartzite it constitutes, south of Marquette, three prominent ranges, the first including Mount Mesnard, the second being south of the Archean island in secs. 2 and 3, T. 47 N., R. 25 W., and the last being adjacent to the Archean to the south. As the formation varies from a pure vitreous quartzite to a slate, its resisting power is very diverse, and its complicated folding gives a very irregular distribution to the different belts, so that, while the ranges have the distribution mentioned, the topography in detail is exceedingly rough. In crossing the formation one climbs a steep ledge, plunges into a sharp ravine, then ascends another bluff, to again climb down; so in crossing a range one traverses a series of exceedingly steep ridges.

FOLDING.

At the east end of the district the quartzite is folded into two closely compressed east-west synclines, with a central anticline, the quartzite occupying the entire breadth of the Algonkian in the section just east of the State prison. (Pl. XV, Sec. XV.) East of this line the overlying dolomite appears in the southern syncline. In the section running south from Mount Mesnard both the northern and southern synclines show the overlying dolomite, while in the central anticline erosion has cut to the Archean, and north of this has appeared another syncline. (Pl. XV, Sec. XIV.) West of Mesnard the northern belt of quartzite has a monoclinal dip, vertical or south at a very high angle. When examined in detail, however, it is found in its slaty phases to be rolled into a set of minor overfolds, which, in passing from the Archean toward the center of the Algonkian, show steadily higher and higher members. In the southern belt the quartzite north of Lake Mary constitutes a shallow synclinal trough. (Pl. XV, Sec. XIII.)

PETROGRAPHICAL CHARACTER.

Macroscopical.—Petrographically the formation consists of conglomerates, graywackes, and graywacke-slates and quartzites, with all gradations between the different phases, although quartzite is the predominant rock. Where rocks of the formation are found in contact with or close to the surrounding granite, they are a coarse granite conglomerate, or a rock which may be called a recomposed granite when the constituent particles composing the rock are the separate mineral particles of the Basement Complex. The conglomerate is magnificently exposed west of Lake Mary in the SW. ¼ sec. 9 and the SE. ¼ sec. 8, T. 47 N., R. 25 W. It may also be well seen at and east and west of the line between secs. 1 and 2 of the same township, and at other places. With the fragments of granite are apparently many of vein quartz, and a few of red jasper, of chert, and of quartz rock. In some cases the bowlder-bearing granite-conglomerate passes into a less conglomeratic, reddish rock, which closely resembles the original granite.

On the north side of the trough north of Mud Lake in sec. 29, T. 48 N., R. 25 W., the lowest horizon is again a basal conglomerate, the numerous fragments being derived mainly from the granites and schists of the Northern Complex, the latter being more abundant because immediately adjacent. The fragments vary from those of minute size to bowlders 2 or 3 feet in diameter. Here no fragments of chert or jasper were found.

The basal conglomerate at Mud Lake usually passes quickly into interstratified slate and graywacke, and then into a quartzite. The slate and graywacke are very closely folded, there being many reduplications of the same stratum, the whole having, however, a southern monoclinal dip, and the axes of the little folds pitching steeply. So close has been the compression that the more resistant belts of graywacke in the slate have been broken into a Reibung's breccia. In some places the folding has been so severe as to entirely destroy the thin belts of graywacke, producing out of it large numbers of pebbles and bowlders. All stages of the transition are found between the continuous belts of graywacke and the pseudo-conglomerate in the slate.

The slates and graywackes usually pass quickly into the typical quartzite of the formation. Within the Mesnard formation is an interstratified conglomerate, from a few inches to 40 feet in thickness, in which are abundant fragments of ferruginous schist, of quartz, of chert, and of jasper.

The quartzite is in general a rather pure vitreous quartzite, very massive in hand specimens, but in the ledge often showing distinctly the bedding, and not infrequently passing into slaty phases. In many places at the east end of the Mesnard range, the original ripple-marked surfaces of the layers are observed. The intricate windings of the conglomeratic chert and jasper pebbled layer were traced out, and were of great assistance in determining the structure. Where the folding has been close, the quartzite passes into a very vitreous rock, or even into a quartz-schist. The vitreous rock is produced by extensive fracturing, or even brecciation and the filling of the resultant minute and large cracks with vein chert or quartz. The veins vary from those of minute size to those several inches across, and in some cases they anastomose through the quartzite in every direction. This secondary material often closely resembles the original strained or granulated quartz grains, but the rocks as a whole take on a peculiar aspect, and have been called cherty quartzites.

At the top the quartzite passes into slaty phases, and these grade into slate, a belt of which, from less than 30 to 100 feet thick, separates the quartzite from the Kona dolomite. The Mesnard quartzite may then be divided into four members: (1) conglomerate, (2) slate and graywacke, (3) quartzite, and (4) slate. The quartzite is the predominant member. Slates and graywackes are locally intermingled with the quartzites. A single section showing all the phases is rarely found, and exposures are not sufficiently numerous to enable one to make these subdivisions in mapping.

Microscopical.—The conglomerates have two phases: (1) those that are coarse and distinctly show the conglomeratic character, and (2) those that are composed of finer detritus, in some cases so closely resembling granite in the field that they have been called recomposed granite.

(1) The majority of pebbles in the conglomerate are found to be more or less decomposed granites, gneisses, and green schists, of all the varieties found in the Basement Complex adjacent. They vary from rounded to angular. In some cases they are so closely packed together as to have between them but little of a finer matrix; in other cases it is abundant. The matrix consists largely of simple grains of quartz and feldspar, which are, again, in a finer clayey and cherty background. In some cases in this matrix numerous distinctly rounded grains of chert are present. Less common than the ordinary pebbles derived from the Basement Complex, but still plentiful, are others of exceptional interest. Certain of these are altered schistose rocks, having a gray complex background apparently composed mainly of kaolinite, quartz, and sericite, heavily impregnated with secondary iron oxide, which also in many places stains the matrix. Slides from the banded jasper pebbles differ but little from the ferruginous jasper of the iron formation. They are exactly similar to the small cherty fragments in the background. It is, perhaps, possible that these rounded chert fragments are of dynamic origin, being produced by breaking asunder the infiltrated cherty matrix and grinding the fragments over one another. The large jasper fragments were probably derived from jasper bands in the green schists, or were formed by the brecciation of secondary veins of jasper in the Mesnard formation itself. All of the quartz grains show undulatory extinction, and many of them are distinctly fractured.

(2) The recomposed granite, which in hand specimen so closely resembles the original granite as to be discriminated from it only by a close examination, in thin section consists of a matrix composed mainly of cherty quartz, with some kaolin and sericite, within which are closely packed simple, distinctly rounded grains of quartz and feldspar, and also complex fragments of the two. As the grains are often large, single interstitial areas of secondary chert are of considerable size.

When the recomposed rocks are much sheared they have in hand specimen, as has been said, a very close resemblance to the original granitoid gneiss. However, in thin section there is present in the fragmental rock a gray kaolinic, sericitic, and quartzose background, which contains numerous large, simple, and complex grains of quartz, many of which have forms characteristic of granite, but the majority of which are distinctly rounded, even when elongated or granulated. The feldspathic detritus has completely decomposed. The original gneiss, upon the other hand, shows a granitic structure, and contains recognizable, although much altered, feldspars.

The conglomerates grade into graywackes and graywacke-slates. These have a clayey background in which are set well-rounded grains of quartz and various feldspars. The different rocks vary from those in which the clayey matrix composes nearly the entire rock to those in which it is sparse, the innumerable quartz and feldspar grains coming in contact with one another. The particles vary in coarseness from those of very small size to those of considerable magnitude. Ordinarily the quartz grains are enlarged, and occasionally the feldspar also. Usually both the quartz and feldspar show undulatory extinction. In the more sheared phases the quartz grains are broken or granulated. With this appears a good deal of secondary cherty quartz and sericite. The most altered phases pass into sericite schists. In this case we have, making a background, innumerable flakes of sericite arranged in a parallel direction, and polarizing together.

The graywackes pass into typical quartzites, composed mainly of well-rounded, enlarged grains of quartz. All of the quartz grains show undulatory extinction, and in some of the slides they are fractured through and through, and elongated. When the pressure has been moderate, the fractures frequently develop in two rectangular systems, each breaking the quartz grains into many parallel plates, and the two combined forming numerous rectangular, minute fragments. In places where the fracturing has been extreme, many cracks and crevices have formed, and these have become filled with secondary silica, which took a cherty or finely crystalline form. These veins vary from those of microscopic character to those so wide as to furnish hand specimens. In some cases a later dynamic movement has brecciated the whole, producing pseudo-pebbles of chert.

From the macroscopical and microscopical descriptions of the Mesnard formation it is plain that there has everywhere been interior movement. Even in the least-altered phases of the rock every grain of quartz shows the effect of strain. From this least altered phase there are all gradations to those phases in which the rock has become a mass of shattered débris, which has been subsequently cemented by cherty quartz. Moreover, after the first shattering and cementation, there has been a later folding, which has again shattered the rock, including both the original constituents and the secondary cherty quartz. This broken rock has again been cemented by later infiltrating silica. In certain parts of the formation, where the relief has been largely by shattering, the clastic character of the original grains is usually still marked, and they are easily discriminated from the secondary cherty quartz. In other phases of the rock, the stresses have been relieved by the movement of the mineral particles over one another, and their granulation, rather than by the formation of large cracks and crevices. In this case the rock becomes a schist, the minute interspaces, however, being filled as before by secondary cherty quartz and by the development of sericite. Between the phases in which the relief is largely by brecciation and those in which it is largely by shearing there are all gradations, an intermediate phase showing the partial granulation of the fragmental grains, their cementation by silica, and at the same time numerous veins of secondary cherty quartz. As has been said, the extreme alteration of the original quartzose sandstone has resulted in peculiar, vitreous, cherty-looking quartz rocks, and that of the original feldspathic débris has resulted in a sericite-schist. The fact that the sandstones became cherty brecciated rocks and that the coarse and fine muds became schists is probably explained by the brittle character of the first and the plastic character of the second, one yielding mainly by fracture, the other mainly by flow.

RELATIONS TO UNDERLYING FORMATION.

The fact that basal conglomerates are found at various places near the contact of the Mesnard quartzite and the Basement Complex has already been mentioned, and the localities at which these conglomerates occur have been indicated. These contacts are of such character as to indicate that the Mesnard quartzite is separated from the Basement Complex by a great unconformity. Since in these basal conglomerates are numerous pebbles and bowlders of granites, gneisses, and schists from the Basement Complex, the complex history of the Archean was essentially complete before the Mesnard quartzite was deposited. Erosion had before this time cut so deeply into it as to bring to the surface in some places coarse-grained granites and in other places the truncated, foliated layers of the schists and gneisses. In the localities where the basal conglomerates occur, the proof of the unconformable relations is conclusive. In other localities the granite was apparently decomposed before the deposition of the quartzite, and here, as has been said, it yielded its small separate mineral particles to the overlying rock. This recomposed rock has been thoroughly cemented. During the subsequent folding shearing has taken place along the junction, resulting in the development of parallel schistosity in the original granite and in the recomposed rock. In such cases it is difficult or impossible to indicate the exact contact between the Basement Complex and the Mesnard quartzite. Such localities led Rominger to believe them to be cases of progressive metamorphism, the granite being a metamorphosed sedimentary rock. Later he abandoned this position. One of the best localities in which to observe this apparent gradation between the gneissoid granite and the quartz-schist is just north of the little granite knob on whose south side is the west quarter post of sec. 1, T. 47 N., R. 25 W. The contact between the Mesnard quartzite and the Archean affords an excellent illustration of the principle that crystalline gneissoid granite may grade step by step into a rock which is an unquestionable quartzite, there being no sharp line of demarcation between the two, and yet between the two formations there really being a profound unconformity.

THICKNESS.

As the Mesnard quartzite is the lowest formation of a transgressing sea, it doubtless originally varied in thickness, this being due to irregularities of the Archean basement. This irregularity in the basement is indicated by the fact that the quartzite belt is in one place scarcely more than 150 feet across. As the dips are here vertical, this may be taken as the thickness of the formation. From this thickness the quartzite shows a continuous exposure at Mount Mesnard of 700 feet, which with an inclination of 80° corresponds to a thickness of 670 feet. In other places the belt is much wider than this, but here the increased width is plainly due to folding, and even at Mount Mesnard the interstratified belts of slate and graywacke may contain minor rolls which have escaped observation and the real thickness of the formation be less than 600 feet.

SECTION II. THE KONA DOLOMITE.

The name Kona dolomite is given to this formation because the Kona Hills, rising from the east shore of Goose Lake with precipitous cliffs and large bluffs, are composed of typical rocks of the formation, and because dolomite is upon the whole the predominant rock.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Starting at Mount Mesnard (see Pl. XIII) the area covered by the Kona formation rapidly widens in passing westward. From south of Mud Lake the belt again narrows in going toward the west, until at Morgan Furnace it is only about a sixteenth of a mile wide. Farther to the west no exposures of this limestone are found, but its horizon may be represented by a belt of slates and quartzites east of Teal Lake.

On the south side of the Algonkian the formation has a much more irregular distribution. Starting at the sand plain just west of Lake Superior, it extends west nearly half a mile, where it disappears. About a mile to the westward southeast of Lake Wabassin the formation again reappears and extends westward as a belt a third of a mile wide. As it reaches Carp River the formation swings southwest and then south to Tigo Lake. Here a small arm goes to the southeast across this lake toward Lake Mary, but the main belt continues to the southward. About a mile west of Lake Mary it widens out into a broad area, varying from a mile to 2 miles in width, and extends to Goose Lake, the last exposures of the formation being found on the east side of this body of water. North of the Archean island in secs. 2 and 3, T. 47 N., R. 25 W., the limestone also appears just north of the Mesnard quartzite in a narrow belt. The real extent of this area of dolomite it is impossible to give, as the Potsdam formation occupies much of the valley of the lower reaches of the Carp River.

Almost coextensive with the distribution of the formation are the exposures, they being abundant and prominent throughout most of the area. However, some of the most readily accessible places at which the formation may be studied are the exposures east of Goose Lake and those south and west of Wabassin Lake.

At Goose Lake, facing the southeast arm, the largest exposures form bold, almost vertical cliffs, 200 feet high. These cliffs slope rapidly to the north, following approximately, with a somewhat regular incline, the dip of the formation. About one-half mile east of the lake is a prominent north-south range of hills, called the Kona Hills, the ragged peaks of which rise from 300 to 400 feet above the water. It is from these extensive and typical exposures that the formation is given its name.

As a consequence of the complicated folding of the formation below described, combined with the very different resisting power of the different layers, the topography of the formation is exceedingly jagged. The exposures constitute a set of sharp and abrupt cliffs, cut by ravines or separated by drift-filled valleys. Where north-south and east-west folds both occur the valleys cut across one another at right angles in two systems, leaving roughly rectangular masses of rock between. In places where the folds have a pitch the layers may form a semicircular outcrop with vertical walls. Rather moderate dips prevail over much of the area, and in traveling over the belt one has to climb a series of steep hills, each of which is composed of a number of almost vertical, ragged cliffs. The descent from the elevation is of much the same character. The weathered surfaces of the ledges, also, are sharp and ragged in a minor way. The cherty layers form sharp ridges. The quartzite layers project in less jagged forms. Geodal concentrations of quartz protrude from the surface of the limestone. The dolomite has dissolved from the cherty and quartzose layers, giving them a rough, vesicular appearance.

FOLDING.

The major folding (Pls. XIII and XV Secs. X–XV) of the formation will be considered in connection with the general geology of the district. It here may be said that the formation has been affected by both east-west and north-south thrust. In some cases the east-west folds are more conspicuous, in others the north-south, while in other areas the folds are about equally prominent in both directions, although even here the folds of one set have less amplitude and less length than those of the other. As a consequence of the above, each fold has a pitch, which may be slight or very steep. Still further to complicate the structure of the region, the major folds in each direction have superimposed upon them secondary folds, and upon these are tertiary ones. In some cases, as in the largest belt east of Goose Lake, the pressure has not been so great as to give the folds very steep inclinations, the dips usually being not more than 20°, although occasionally as high as 50°. As a consequence of the nearly equal power of the folding forces in each of the directions in this broad area, the ledges give strikes in all possible directions.

To the pressure of folding the limestone has usually yielded without prominent fractures or cleavage. The same can not be said of the interlaminated slates, graywackes, and quartzites. Oftentimes a bed of slate has had developed across it a diagonal cleavage, which stops

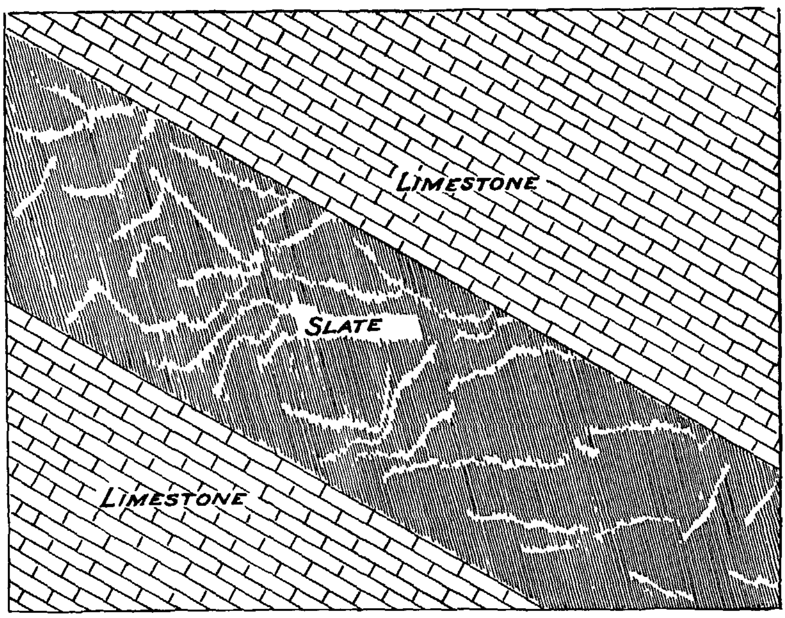


FIG. 11.—Cleavage in slate between two dolomite beds.

abrubtly at the limestone layers (fig. 11). In other cases the cleavage passes into the dolomite itself, as, for instance, at the exposure back of the railroad section-house near Goose Lake. Occasionally the different dynamic movements have each produced a slaty cleavage, so that the rocks break into polygonal blocks. Frequently the layers of chert and quartzite have been fractured through and through by folding, so as to change them into breccias resembling conglomerates. Along the contacts of the dolomite beds and the quartz layers accommodation was necessary, and in places a bed of limestone may be seen bent into a series of anticlines and synclines, the overlying quartzite not being similarly bent, but being compressed and brecciated (fig. 12), thus making a pseudo-conglomerate. The folded

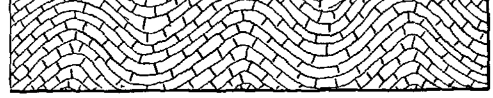


FIG. 12.—Reibung's breccia in cherty quartzite truncating limestone strata.

dolomite laminæ are actually cut away to some extent by the shearing action. The result is that the layers of quartzite cut across the folds of the limestone, as in an unconformable contact, and adjacent to these truncated layers are the pseudo-conglomerates. Such contacts as these, found at many places, strongly suggest an unconformity between the two, but the true explanation is undoubtedly that the apparent unconformity is merely a dynamic phenomenon.

PETROGRAPHICAL CHARACTER.

Macroscopical.—Petrographically the different exposures are very similar. The formation is not a pure dolomite, but is a cherty dolomite interstratified with layers of slate, graywacke, and quartzite, with all gradations between these various mechanical sediments and between these and the pure dolomite. In some exposures the pure dolomite does not constitute more than a third to a half of the belt. The interstratified slates and quartzites are of the same character as those of the Wewe slates and Ajibik quartzites, except that they are apt to be more or less calcareous. The dolomite beds vary in thickness from only a few inches to many feet. But even the solid belts of limestones usually contain very thin layers, which in places are in part fragmental, but which are usually wholly or in large part secondary chert. In color the dolomite varies from nearly pure white to dark brown, depending upon its purity, and between these colors are various shades of buff, purple, pink, and red. As the interbedded slates and quartzites also have a wide variation in coloring, the ledges of the formation are very different in their external aspect.

The dolomite varies from aphanitic to coarsely crystalline. Upon the weathered surface the pink and red varieties usually have a dark-brown color, due to limonite. This indicates that the carbonate carries a considerable quantity of iron, the oxidation of which has produced this outer, dark-colored skin. Where the dolomite is most coarsely crystalline, as for instance at the Morgan Furnace, it sometimes contains belts from a fraction of an inch to 4 inches wide, largely composed of pink, coarsely crystalline, and evidently rearranged calcite. As a consequence of weathering, the bands of original sedimentary quartz and of secondary chert protrude, giving a peculiar rough, ridgy appearance.

The exposures at Goose Lake may be taken as types of the exposures of the formation everywhere. The lowest horizon here found is a very impure limestone. Above this follows a succession of interlaminated, impure dolomites, red and black slates, cherts, quartzose dolomites, cherty quartzites, at times brecciated, and occasionally beds of nearly pure quartzite, or even of conglomerate. These various strata may have thicknesses from an inch or less to a number of feet. The layers of quartzite, usually not more than a foot or two in thickness, and oftentimes less, are generally interstratified with the dolomitic slates. In one place ripple marks were seen in the beds above and below a layer of conglomerate. The close intermingling of mechanical and non-mechanical sediments suggests that at the time of the deposition of the lower half of these beds the water was not very deep, and perhaps a shore-line was not distant. The colors of the rocks vary from the dark gray of the slates, through various shades of buff and brown, to nearly white in the case of some of the dolomites or quartzites. Following above these beds are others, comprising all of the foregoing kinds, and also heavy beds of nearly pure, coarsely crystalline, granular dolomite, some of which are 20 feet thick.

After an interval of no exposure the next point to the north on Goose Lake is occupied by coarsely crystalline, nearly pure, pink dolomite, with occasional layers of more finely crystalline material and a few layers of chert. After another interval of no exposure are very large outcrops of similar dolomite, some layers of which, however, are very quartzose and a few shaly. The northernmost exposure is a coarsely crystalline dolomite, containing many nodules of coarsely crystalline quartz. Of the large exposures southeast of Goose Lake probably not more than one-third of the thickness is composed of reasonably pure dolomite, the remaining two-thirds being largely mechanical sediments. Farther to the east the proportion of mechanical material is not so great. The same phenomena are observed in the northern belt of dolomite, the exposures at Morgan Furnace being richer in slates and quartzites than those farther eastward.

Microscopical.—The rocks of the Kona dolomite comprise coarsely and finely crystalline dolomite, cherty dolomite, quartzose dolomite, argillaceous dolomite, dolomitic quartzites, dolomitic slates, dolomitic cherty quartzites, and dolomitic chert.

The compact and apparently least altered purer rock has a background consisting of finely granular dolomite, the separate granules of which are largely rhombohedra. These very finely granular rocks vary to those which are more and more coarsely crystalline, and these grade into those into which coarse crystals of dolomite compose most of the rock. It is probable that in these coarser rocks there has been a recrystallization. This is indicated in one case by a remarkably beautiful zonal strûcture, shown by all of the large rhombohedra of dolomite.

The purer phases of dolomite pass into those in which the dolomite is heavily stained with iron oxide. In some cases on the weathered surface is an outer layer of heavily ferruginous material, resulting from the decomposition of the dolomite, and showing that the carbonate is ferriferous.

These nonfragmental rocks by gradation pass on the one hand into the argillaceous dolomites or mica-slates and upon the other into the quartzose dolomites. In the argillaceous dolomites the finely crystalline quartz, feldspar, and other clayey materials are intimately intermingled with the granules of dolomite. By a further decrease of the dolomite the rocks pass into the dolomitic slates. Those which show the fragmental material in a dolomitic background are placed with the dolomites. Those which show a fragmental background in which the dolomite occurs are placed with the slates.

When the detritus is coarse the rocks become quartzose dolomites. In these we have a large amount of fragmental quartz, in well-rounded, enlarged grains. When the quartz grains are buried in a background of dolomite they are called siliceous dolomites. By a decrease of the dolomite we have a sparse matrix of carbonate in which numerous quartz grains are set, and then the rock becomes a calcareous quartzite. In some cases the alternations of coarse and fine material are in minute layers a fraction of an inch across, having alternately coarse and fine grains of quartz and greatly varying amounts of dolomite. In other cases thick beds are wholly of the calcareous quartzite.

The rocks of the formation, whatever their lithological character, have been shattered by dynamic action, and frequently become Reibung's breccias. These breccias, which when much sheared resemble true conglomerates, differ from them in the usual angularity of the fragments and in containing no material from an extraneous source. The purer dolomites when merely shattered have been cemented by finely crystalline cherty quartz, or by coarsely crystalline dolomite, or by these two combined. The brecciated phases show numerous irregular, roundish, complex fragments of the granular dolomite. The angularities of these dissevered fragments are frequently the reverse of the fragments adjacent, proving conclusively that they have been broken apart. In a more extreme phase of the dynamic action the complex fragments of the granular dolomite have a subangular or roundish appearance, so that the rock as looked at with a low power resembles a conglomerate. These dissevered fragments are united by cherty quartz, by coarsely crystalline dolomite, or by the two interlocking. In some cases this secondary cherty quartz has impregnated the rock through and through, so that minute irregular veins of chert or geodal areas of chert are scattered through the dolomite. In a still further stage of silicification but a small amount of granular dolomite may be seen in the chert veins. As a result of further silicification considerable belts of chert are found interlaminated with the bands containing less chert. Frequently these belts have oval terminations, or run out abruptly. Oftentimes after a first dynamic action and silicification the rocks have become brecciated again, and have again been cemented by later infiltrating silica. In this case we have a cherty dolomite or a chert breccia, with a cement of newer chert. It is generally possible to discriminate the earlier and later chert by the slightly different crystalline characters which it has, and also because the later chert is sometimes mingled with oxide of iron.

The argillaceous and siliceous dolomites are brecciated in the same manner, and have been cemented in the same way as the purer dolomites. In this case we have both fragmental quartz and secondary cherty quartz intermingled. The original quartz grains uniformly show undulatory extinction or fracturing. Frequently during the folding the grains of quartz and feldspar have been broken out of their background and have fallen into the crevices. These are surrounded by and embedded in secondary infiltrated cherty quartz and dolomite.

The slates and quartzite interstratified in the Kona dolomite are not here described, as they are in all respects similar to the Wewe slates and the Ajibik quartzites subsequently described, with the exception that they are more or less dolomitic.

The foregoing study of the thin sections of the Kona formation shows that it has been shattered throughout. From the field observations it was apparent that the formation had been much broken by dynamic action, but the completeness of this shattering and brecciation was appreciated only by a study of the thin sections, every one of the numerous slides showing these phenomena to a greater or less degree. It thus appears that not a half-inch cube has escaped. It is believed that this indicates that the rock when folded was not buried under so great a load as to be beyond the sustaining power of the rocks. Upon the other hand, since there are no prominent faults, and since the formation as a whole has yielded to the folding forces and is bent and bowed in a complicated fashion, as a continuous formation, it is thought that it was buried under a considerable thickness of strata.

RELATIONS TO ADJACENT FORMATIONS.

The Kona dolomite varies through a slate into the Mesnard quartzite below. This slate appears to be a thin, persistent formation. Its thickness varies from less than 30 feet to 100 feet. In many other places it appears thinner than this minimum, but it is not often that the exact contact between the slates and the formations above and below it can be seen, there usually being, however, sufficient room for the slate belt between the quartzite and the dolomite. This slate may be well observed at Mount Mesnard, where it forms a little valley separating the quartzite peak on the north from the marble peak on the south. The slate may also be well seen just west of Wabassin Lake in sec. 2, T. 47 N., R. 25 W., where the westward-plunging synclinal of the Kona formation causes the slate to appear immediately beneath the limestone. This belt of slate, which was once a shale, probably marks the time of deepening waters, when the conditions favorable to the deposition of a sandstone changed to those favorable to the formation of a limestone.

Above, the dolomite, by a lessening of the calcareous constituent, gradually passes into the Wewe slate. The appearance of this formation may have marked a time when subsidence had ceased, and the limestone had been built upward until the finer-grained mechanical sediments could be carried by the waves. That this is probable, rather than that the sea had deepened so much as to make the limestone formation impossible, is indicated by the fact that above the Wewe slate follows the Ajibik quartzite, a still coarser mechanical sediment.

THICKNESS.

As a consequence of the complicated folding of the district, it is exceedingly difficult to give any accurate estimate of the thickness of the Kona dolomite. It doubtless varies much, perhaps reaching its maximum somewhere near the central part of the area, and thinning out in passing to the west. South of Mud Lake the formation has an almost continuous exposure for 1,500 feet, with a dip to the south varying from 78° to 90°. If there were no minor folds, and calling the average dip 80°, this would correspond to a thickness of about 1,375 feet. However, it is certain that just to the north of this lake the slates are in a series of sharp, isoclinal folds; and that this is true for the limestone, to some extent at least, is more than possible. How much this maximum thickness should be decreased on account of this uncertain element of the problem it is difficult to estimate, but it is wholly possible that the thickness as above calculated should be reduced one-half. At Goose Lake, as has been said, there is a continuous exposure of the formation for a considerable distance. Here the thickness of the layers was carefully measured and found to be 225 feet, with a possible error of 25 feet. If the formation is supposed to have the same dip to the northward for the remainder of the detached exposures along the east shore of Goose Lake, this thickness may be increased by 150 or 200 feet.

West of Tigo Lake the formation is exposed almost continuously for a distance of 1,300 feet. The dip here varies from 25° to 40°, averaging perhaps 30° or 35°. Calling the average dip 30°, this would give a thickness of 650 feet. Although the limestone occupies an area as broad as 2 miles in certain places, it can not be asserted, on the present information, that the maximum thickness of the limestone is more than 700 feet, although it may be twice this amount.

SECTION III. THE WEWE SLATE.

The name Wewe slate is given to this formation because it occurs in typical development on the Wewe Hills west of Goose Lake, and because the predominant rock is a slate. With the slate are graywackes, conglomerate, mica-slates, and in places mica-schists.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Starting at the west side of Goose Lake (see Pl. XIII), the belt extends in a general westerly course for about 3 miles, having, however, for this distance tortuous boundaries and a greatly varying width. It will be seen that the Kona dolomite begins east of Goose Lake as a broad belt. The Wewe slate, following above the limestone, should appear both to the north and south of this belt. On the south, however, the formation is exposed only in secs. 13 and 24, T. 47 N., R. 26 W., and in sec. 18, T. 47 N., R. 25 W., where, however, it extends but a short distance before it is hidden by the Pleistocene sands. The northern arm of the slates shows outcrops in secs. 11 and 12, T. 47 N., R. 26 W., and very numerous outcrops west of the Kona dolomite in secs. 5, 6, 7, and 8, T. 47 N., R. 25 W. In this area the slate belt swings from an easterly course to a northerly, and finally to a westerly one, and extends along the southern side of the northern limestone for an unknown distance westward. There are no exposures in this area, and whether it dies out before the slates and quartzites east of Teal Lake are reached is uncertain. The black slate occurring at a somewhat persistent horizon between thick beds of quartzites in secs. 32 and 33, T. 48 N., R. 26 W., may be the most westerly representative of the northern belt. Farther west the formation has not been deposited, the sea encroaching from the east not having at this time yet overridden this part of the district.

The slate being a less resistant formation than the Kona dolomite below or the Ajibik quartzite above, is, in general, marked by valleys, and consequently the exposures are few for much of the area of the belt. The two exceptions to this statement are the numerous prominent exposures in secs. 5, 6, 7, and 8, T. 47 N., R. 25 W., and the exposures west of Goose Lake. The appearance of the first group of outcrops is due to the cutting action of Carp River, which flows over the ledges in a number of rapids and cascades. The many exposures west of Goose Lake are due to the fact that here was the westward limit of the shore-line at this time, and therefore the slates deposited at this place largely took on a graywacke and conglomeratic character and thus became more resistant. Also they gain in prominence by the presence of several resistant Archean islands, which they surround.

FOLDING.

The broad belt of slate running north and east from Goose Lake, then swinging to the north and west, has no especially marked features, as the slate everywhere dips away from the Mesnard dolomite below, and thus forms a great westward-plunging syncline, with the eastern termination in secs. 5, 6, 7, and 8, T. 47 N., R. 26 W.

However, the folding in the two areas east and west of Goose Lake is interesting and peculiar (Pl. XV, Sec. XI). In secs. 13 and 24, T. 47 N., R. 26 W., and secs. 18 and 19, T. 47 N., R. 25 W., the slate has been affected by both an east-west and a north-south folding. The north-south pressure has folded the slates into a series of minor rolls, and the same layer is repeated many times. The east-west pressure has bowed them into anticlines and synclines. The character of this folding is particularly well shown by the almost continuous section which is observable along the east parts of secs. 13 and 24. A syncline causes the little east-west folds to plunge to the eastward from the west side of the area, and to the westward from the east side of the area. The slate originally arose above the Kona dolomite to the east, north, and west, but has been removed from it by erosion.

West of Goose Lake it has been said that the slate covers a belt of very greatly varying width, in which are Archean islands. The largest of these areas covers a considerable part of the central portion of sec. 23. Another area is southwest of this in secs. 22 and 23, and two other areas occur in sec. 22, one at the center of the section and the other in the center of the southwest quarter. The conglomerates, slates, and quartzites in sec. 23 and in part of sec. 24 have a quaquaversal arrangement around the oblong Archean area of sec. 23. In other words, the slates and quartzites constitute a part of an east and west anticline, which plunges both to the east and to the west from the center of sec. 23. The strikes about this and the other areas are northwest-southeast except at the ends of the areas; the dips are all to the northeast, showing that the folds have been pushed over from the northeast or pushed under from the southwest. The dispersed character of the small Archean areas, and the fact that basal conglomerates cover a considerable area, are taken to indicate that there are several subordinate folds in this part of the district.

PETROGRAPHICAL CHARACTER.

Macroscopical.—For the areas north and east of Goose Lake, the rocks of the formation are slates and graywackes. Southwest of Goose Lake the lower part of the formation becomes a quartzite or quartzite-conglomerate. These conglomerates, reposing as they do upon the gneissoid granites, are very largely composed of detritus derived from them. Immediately adjacent to the Archean cores on the Wewe Hills, in the centers of secs. 22 and 23, the basal rocks are no more than a mass of granite blocks, cemented by fine débris of the same material. An intermediate rock is a coarse-banded, feldspathic quartzite, which in the field very closely resembles the original gneissoid granite. From these basal members there are all gradations to graywackes, novaculites, and slates. The slates in places contain pebbles or bowlders of many kinds, and thus become slate-conglomerates. In the higher part of the formation the slates and graywackes pass by interstratifications and gradation into the Ajibik quartzite.

The ordinary detritus of the formation differed from very fine mud to coarse, sandy mud, and there are frequent alternations between the various phases. As the result of the compacting and modification of these beds, we have shale, slate, novaculite, and graywacke. The color of these rocks varies from red to black, with various shades of buff and brown, depending upon the quantity and condition of the iron oxide. While many minor alternations occur, one part of the Wewe formation may be as a whole finer grained than another part. For instance, at the exposures in the southeast part of sec. 13, T. 47 N., R. 26 W., the black, finer grained phases of the slates occupy a higher horizon than the coarser, novaculitic-looking phases.

As a consequence of the folding, certain of the slates, and especially those that are fine-grained, have had developed in them a slaty cleavage. Also, along the zones of sharpest folding and of shearing the rocks pass into mica-slate, or even into a rock approaching a mica-schist. In some cases they approach in appearance Knoten-Schiefer. As a consequence of the slaty cleavage and schistosity in many ledges, it is difficult to determine the true strikes and dips. However, the true bedding is usually indicated by frequent alternations of darker and lighter colored materials. Often parallel to the bedding are cherty-looking layers, which frequently have a lenticular character, the oval areas lying end to end, with intervening slate, or overlapping. When followed closely, they are found in places to cut in a minor way across the bedding. Often they branch into two or more parts, or send out stringers into the slate. In other cases the cherty or quartzose layers follow the schistosity rather than the bedding. Finally, the slates and graywackes are usually cut by numerous veins running in all directions. A close examination shows that whether these cherty parts follow the bedding or the schistosity, or cut the rock at random, they are secondary infiltrations. In many places the orographic movements have been so powerful as to shatter the rock through and through (fig.13), or even to produce breccias (fig. 14), the fragments of which are in some places tolerably well rounded by dynamic action. The fragments vary in size from minute ones to great blocks several feet in diameter. The shattered rocks or the fragmen s of the breccias, have been cemented by vein quartz, jaspery quartz, and hematite, sometimes one and sometimes two or three together. At one exposure the veins of hematite are later than the white quartz, and the jasper is later than the former, and the fragments have around them in some cases, in con-

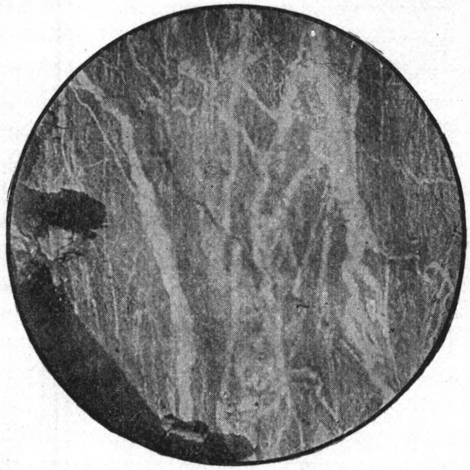


FIG 13.—Shattered slate cemented by vein quartz, from NE. ¼ section 21, T. 47 N., R. 26 W.

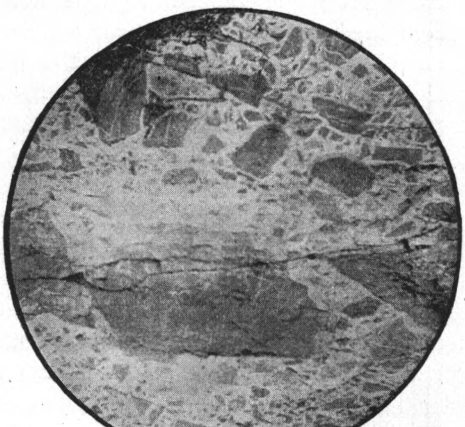


FIG. 14.—Brecciated slate cemented by vein quartz, from same locality as fig. 13.

centric parallel zones, quartz, hematite, and jasper, although even at this place the quartz sometimes fills the entire space. Where the veins of hematite and jasper are of considerable size they can not be discriminated from the hematitic jasper of the iron-bearing formation. In places the amount of hematite is so great in the breccia that the material has been prospected for ore. The secondary character of the jasper and hematite in the case of these breccias can not be doubted, and this has a bearing upon the origin of the jasper and hematite of the iron-bearing formations. These breccias are discriminated from true conglomerates by the fact that all of the fragments are derived from the slate. Also, the breccias vary into slate by imperceptible stages, both along the strike and across it; and finally, while many of the fragments have been rounded so as to resemble those produced by water action, others have an irregular character which is not consonant with a water origin.

Microscopical.—The main varieties of rock discriminated in thin section are basal conglomerates and quartzites, graywackes, novaculites, slates, and slate-conglomerates.

The quartzites and conglomerates differ from each other only in that the conglomerates have large fragments. In other words, the conglomerates have a quartzite base. The complex fragments found in the conglomerates in each locality are predominantly of the particular rock immediately subjacent, but with these are fragments derived from other sources. These fragments comprise white sheared granite, described on p. 516 as sericitic quartz-schist, white sheared granite containing large crystals of feldspar, pink granite, and gneissoid granite, a peculiar, very feldspathic pegmatite, fine-grained chloritic schist or gneiss, sericite-schist or gneiss, quartz pebbles, and other varieties of rock. All of these pebbles show dynamic effects. Many of them have been broken and cemented by finely crystalline and secondary quartz. Microcline cleavage is also developed in the potash feldspars. The quartz grains uniformly show undulatory extinction; many of them are distinctly fractured, and these fractures are sometimes according to a rectangular system. The quartz pebbles are found to consist of intricately interlocking or closely fitting, roundish granules of quartz, but in no case do any of these distinctly show a fragmental character, and they are believed to have been derived from granite or from vein quartz. The chloritic and sericitic schists and gneisses have in some cases, at first glance, a fragmental appearance, but the more closely they are studied the more do they appear to be completely crystalline rocks. To describe the fragments of the conglomerates in detail would be a repetition of the description of the rocks of the Basement Complex.

The quartzite or quartzite background of the conglomerates contains an abundant, very finely crystalline groundmass of sericite, kaolin, and quartz, with a little chlorite, and is often impregnated with iron oxide. In this groundmass are simple and complex grains of quartz and less abundant grains of the various feldspars, and as the rocks become coarser grained these pass into the complex areas composed of quartz and feldspar. The groundmass of these rocks and that of the fragments contained in them are the same, and the structure is somewhat similar to the sheared gneissoid granites or sericitic quartz-schists of the Archean. (See p. 516). Also, many of the simple and complex quartz grains have a granitic appearance, having been but little water worn; but some of the grains show a distinct water-worn character, and they are rarely enlarged. In the quartzites there are usually alternating layers of finer and coarser material, while in the gneissoid granite the laminæ are all alike. The recomposed rocks contain a much larger amount of secondary iron oxide than the schistone granites, and in the folding they have been more broken, thus producing distinct cracks and minute cavities, which have become filled with finely crystalline secondary quartz. The thin section thus enables us to discriminate the recomposed rocks from the original sheared gneissoid granite. The feldspars of the quartzites often are sufficiently fresh to show distinctly their twinning, but all of them are more or less kaolinized. Frequently the feldspars have largely or wholly decomposed into a complex, interlocking, finely crystalline mass of sericite and quartz, chlorite and quartz, biotite and quartz, or combinations of these. In an intermediate stage there is with this residual feldspar. Often during or subsequent to this decomposition a good deal of secondary iron oxide has entered, and in these cases we have in place of the feldspar grains an interlocking mass of iron oxides, quartz, and sericite.

By a change in the character of the groundmass and a decrease in the size of the fragmental grains, the quartzites pass into the graywackes. There is present in the groundmass the same constituents as in the quartzites, but chlorite is abundant, and intermingled with the groundmass are very small fragmental grains of quartz and feldspar, and frequently a large amount of secondary iron oxides, chiefly hematite and magnetite, often with distinct crystal outlines. In some cases a film of oxide of iron is around each of the individual grains of quartz. In the background, as the rocks become sheared, the leaflets of sericite and biotite have a tendency to a parallel arrangement. The coarser quartz grains uniformly show undulatory extinction or fracturing, with the usual rectangular system of cracks. The smaller quartz grains, when buried in an abundant matrix, and therefore not pressed against one another, are freer from these pressure effects, and in some cases they are not seen at all. The quartz grains are much more frequently enlarged than in the basal quartzites. The feldspars, while often rather fresh, show all phases of decomposition to sericite, biotite, or chlorite and quartz and iron impregnation, described in the conglomerates.

By a decrease in the size of the coarser fragmental grains, the graywackes pass into the slates. In these slates, because of the smaller size of the feldspar grains, their decomposition is much more common. On account of the more plastic character of the slates, there is frequently developed in them a slaty cleavage or schistose structure, the ordinary cleaved slates passing into mica-slates, and occasionally into sericite-schists. In passing from the less sheared to the most sheared phases, there is an increase in the perfection of the arrangement of the sericite leaflets in a uniform direction. As in the graywackes, the rocks are usually impregnated to a greater or lesser degree by iron oxide, and frequently very heavily so. The iron oxide includes limonite, hematite, and magnetite, the two latter often being in large part in well-defined crystals, and sometimes in veins. Frequently the slates consist of layers of differing degrees of coarseness, sometimes a half dozen fine and coarse laminæ being observed in a single section. In these cases the coarser bands are more likely to be heavily iron stained, the accommodations apparently having formed cracks and crevices to a greater degree than in the finer and more plastic interlaminated layers.

The slates and graywackes at times become conglomeratic, so that whole exposures are slate-conglomerate, or else the conglomerate layers are interstratified with the ordinary slate and graywacke. These slate conglomerates bear exactly the same relation to the slates and graywackes that the basal conglomerate does to the quartzite—that is, there are pebbles and bowlders in the slate or graywacke background. These pebbles and bowlders are identical in lithological character with those of the basal conglomerate, but, upon the whole, they are better rounded. In certain places the later dynamic movements which these slate conglomerates have undergone have brecciated them, so that with the water rounded fragments are apparent pebbles of slate and graywacke. A close examination of these in the field, and especially in thin section, shows that they have angular forms and are clearly produced by the brecciation of the rock itself. This occurrence was particularly confusing, as the rock is an undoubted conglomerate, and yet a conglomerate which is partly autoclastic.

The novaculites are similar to the slates and graywackes, except that they are very largely composed of very small, rounded grains of quartz and fewer of feldspar, of a somewhat uniform size, with a very sparse matrix of sericite, kaolin, and ferrite. In the field these uniformly granular fine-grained rocks were not discriminated from the secondary chert veins and layers, but in thin section they are wholly different, having the grains distinctly rounded, and not closely fitting, and having the sparse matrix above described. The cherty material, upon the other hand, consists of finely granular, perfectly fitting quartz, free from the clayey constituents, and, if iron oxide is present, it is usually concentrated to a greater or lesser degree in bunches or layers, rather than uniformly disseminated between the particles, as in the novaculites.

The quartzites, interstratified with the higher members of the formation, are in all respects like the Ajibik quartzites hereafter described.

The graywackes, slates, and novaculites, as has been hinted, have frequently had developed in them a slaty cleavage or schistose structure, and have been broken through and through by dynamic action. As a result of this, crevices and cracks have formed parallel to the bedding, parallel to the secondary structures which intersect the bedding, in directions independent of either of these, and between the individual particles of the rocks themselves. These cracks and crevices have been largely cemented by finely crystalline, perfectly fitting grains of quartz, which in hand specimen has a cherty appearance. In other places coarsely crystalline vein quartz has entered. In the readjustments cracks have formed largely parallel to the bedding, and secondary cherty layers have formed in this direction. In hand specimen, in some cases, they might be regarded as truly interbedded layers, but when examined in thin section the secondary character of this vein chert is undoubted. This is shown by the fact that within it are fragments of the original slate, and also from these apparent quartz bands smaller veins of cherty quartz ramify, cutting the slate in all directions. Moreover, as examined in hand specimen, these cherty-looking layers often have a lenticular character, the oval layers lying end to end or overlapping. In one case, where the coarsely crystalline quartz is present, we have the clearest evidence of two dynamic movements, since the crystalline quartz shows undulatory extinction and fracturing, sometimes according to the rectangular system. When the rocks have not only been broken, but interior movement has occurred throughout the rock, the entering quartz has taken advantage of all of these spaces, thus recementing the rock. In some cases, in the background of the slate itself, this secondary quartz seems to be almost as plentiful as in the original material, occurring as little, oval, complex areas, as minute stringers ramifying through the coarser veins, and as single individuals between the fragmental constituents. While the cementing of the shattered rock has been mainly a process of silicification, it has been indicated that a large amount of oxides of iron has also entered. In some instances these oxides of iron are the main constituent of the cementing material, but usually they are subordinate to the secondary quartz. When both are present, they are not uniformly intermingled, but are more or less concentrated in irregular areas or bands. As another result of the shattering of the rocks, the layers have been faulted in a minor degree.

In an extreme phase of fracturing, the rocks pass into genuine autoclastic rocks or Reibung's breccias. In some of these the angular fragments of the slate are separated by reticulating veins of coarsely crystalline quartz, finely crystalline chert or jasper, and hematite. In other cases the secondary material makes a continuous ramifying mass, within which are complex bands and fragments of the original slate, or the separated individual grains. The extreme phases of brecciation more usually occur in the graywackes, the finer grained phases being more plastic and yielding more readily to pressure, and thus developing into slates and schists. In some of the coarser graywackes the relief appears to have occurred along zones of irregular width, and here the grains have been loosened from one another. These zones are indicated by abundant iron impregnation, and are separated from the layers at the side, which have not suffered so much from movement.

RELATIONS TO ADJACENT FORMATIONS.

In all the exposures north and east of Goose Lake, the inferior formation is the Kona dolomite. This dolomite generally grades upward into the slate by a gradual disappearance of the calcareous material. The lower and central portions of the formation are pure slates or graywackes. In some cases the basal horizon of the slate is a chert breccia, undoubtedly of dynamic origin, but resembling a conglomerate. Such breccias may be well seen at the contact between the slate and the Kona dolomite north of the east ¼ post of sec. 13, T. 47 N., R. 26 W. The slate at this particular locality becomes coarser grained in passing toward the base, grading first into a novaculite, then into a graywacke, and then into a brecciated, cherty quartzite. The chert breccia at the contact appears to have been produced from secondary belts of chert, which have appeared within, and perhaps have replaced calcareous layers in the quartzite. When the rock was folded the brittle cherty layers were broken into fragments. This breccia might possibly be taken by a careless observer as evidence of a physical break between the Kona dolomite and the Wewe slate.

West of Goose Lake, below the slate, are islands of Archean rocks. It has been said that here conglomerates have an extensive development adjacent to the Archean cores. In sec. 23, T. 47 N., R. 25 W., and near the central part of sec. 22, T. 47 N., R. 25 W., contacts are exposed between the Archean and the conglomerates, but no contacts were seen adjacent to the area in the southern part of the SW. ¼ sec. 22, although large exposures of conglomerate were found near to those of the granite.

At the west, southwest, and south of the western bluff of the Archean of sec. 23 (see Pl. XIII), the basal conglomerate is well exposed in direct contact with the underlying crystalline rocks. At the west foot of the hill is a solid ledge of the white, sheared, schistose Archean granite. It is in contact with and mantled on both sides by the conglomerate, which is mainly composed of material exactly like the original rock, The fragments and matrix so closely resemble the gneiss that its recomposed character scarcely shows—so intensely sheared is the rock—except upon the weathered surface, where may be seen rounded, protruding fragments of the granite, varying in size from small ones to great blocks. In passing eastward along the south slope of the bluff, the white gneiss of the Basement Complex takes on a different character, here being less altered, and therefore containing pink augen of the original feldspar. In the field, as well as from microscopical study, it is plain that it is a sheared granite. Adjacent to this granite the conglomerate contains predominant pebbles of a corresponding kind. As further evidence of this unconformity, the white and pink sheared granite is cut through and through by veins of red granite, which are nowhere observed to cut the conglomerate.

The contact is again seen in the valley to the south, where the recomposed rock on a little ridge projects east as an arm into the area of the Archean. Here the conglomerate has not been so strongly sheared. The sparse clayey matrix is stuccoed with fragments of the red granite, and the white, kaolinic quartz-schist from the Archean. Many of these macroscopically closely resemble chert. The conglomerate appears also to contain fragments derived from a slate or graywacke. The upper part of the conglomerate, besides containing pebbles of granite and gneiss, contains many pebbles of white quartz, some of which macroscopically appear to be derived from a quartzite; also rare pebbles of chert, jasper, and many of a slaty or schistose rock. The matrix, usually white or pale green, is ordinarily slate, graywacke, or quartzite, but oftentimes it is so fine-grained as to have a novaculitic appearance.

In sec. 22, also, the actual contact between the gneissoid granite Archean axis and the conglomerate is seen. Here are magnificent exposures of great bowlder conglomerates, the granitic fragments of which, of varying sizes, are close together, so that there is but a sparse matrix. In some cases this recomposed rock so closely resembles granite that it is with difficulty that its true character is certainly determined. In cases of doubt, however, the weathered surface enables one to distinguish between the original and the recomposed rocks, as here the granite fragments protrude from the face of the conglomerate. This granite stucco varies up into slate-conglomerate of differing degrees of coarseness, and finally slate is found containing only small pebbles of granite. In some cases, in the finer conglomerate, the particles of the recomposed rock are almost wholly single grains of quartz and feldspar, or are small complex grains of granite. These show a laminated arrangement, and in the hand specimen the recomposed rock very closely resembles the original gneissoid granite. As higher horizons are reached, the slate and slate-conglomerate pass up into feldspathic quartzites, novaculites, slates, and graywackes, of various hues, similar to those in sec. 23, and finally above them appear the pure vitreous quartzite of the Ajibik formation. In a number of places the actual gradations are seen, and the formation line between the two is somewhat arbitrarily drawn.

THICKNESS.

On account of the complicated character of the folding of the slates, graywackes, and conglomerates west of Goose Lake, it is impossible to give even an approximate estimate of the thickness of the formation. Here, adjacent to the shore-line, it is natural to expect it to have a greater thickness than to the eastward, and it is believed that the thickness is very considerable. In sec. 22 there are almost continuous exposures of the slate, all apparently north of the northernmost anticline, and all dipping the same way for a breadth of 1,300 feet. The dip is here 50° to 60°, and this would correspond to a thickness of about 1,050 feet. To this would necessarily be added the thickness of the conglomerate, which should appear below the slate and graywacke. This area is, however, near the northern end of a northeast-southwest anticlinal dome, and the slate shows much brecciation, well-developed slaty cleavage, and, when studied closely, numerous minor rolls; so it is entirely possible that the real thickness of the formation is not more than a third of the above estimate. In secs. 13 and 24, where there are numerous rolls of the slate and quartzite, a close examination showed that there was probably exposed here a thickness of slates not exceeding 200 feet, and perhaps not more than 100 feet. At the numerous exposures in secs. 5, 6, 7, and 8, T. 47 N., R. 25 W., there is little opportunity to get an accurate estimate of the thickness. The calculated thickness west of Goose Lake is probably a maximum, and that east of Goose Lake may be considered a minimum. The average thickness of the formation may perhaps be as much as 500 feet.

SECTION IV. THE AJIBIK QUARTZITE.

The formation is given the name Ajibik quartzite because the predominant rock of the formation is quartzite, and because typical exposures of it occur on the bold Ajibik Hills northeast of Palmer.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Beginning at the south arm of Goose Lake, the formation occupies a broad belt, which narrows in sec. 23, swings south of the Wewe slate, and then gradually increases in width to sec. 28, T. 47 N., R. 26 W. From this place one arm extends to the west for nearly a mile, but the main arm swings to the west of the Wewe slate, and then east, north of the same formation. West of Goose Lake, again, the belt becomes broad, and an arm projects to the southeast between two Archean islands, being bounded on both the east and the west by the Wewe slate. The main belt, reaching Goose Lake, extends north of this area for a mile, then swings eastward, which course it follows for 2 or 3 miles, then swings to the northeast to Carp River. Here it is faulted, but, reappearing again north of the river, it continues its course east, then north, then west in sec. 6, T. 47 N., R. 25 W. It follows this western course to the quartzite range east of Teal Lake, the northern part of which it constitutes. West of Teal Lake it again reappears, here being in contact with the Archean, and follows along this formation to Lake Michigamme.

South of the Negaunee formation in sec. 35, T. 47 N., R. 26 W., there appears a quartzite, placed with the Ajibik quartzite, which extends westward almost continuously to sec. 31. The belt here swings to the north, northeast, north, and finally west again, about an anticline in the Archean, and then extends in a general westerly course to sec. 20, T. 47 N., R. 26 W.; thence northwest to near Humboldt in sec. 12, T. 47 N., R. 29 W. Exposures of quartzite reappear at the base of the Lower Marquette series in the Republic tongue, and from the west side of this area swings to the west and then to the south beyond the area considered. It is doubtful whether this western part of the quartzite is really the time equivalent of the remainder of the Ajibik quartzite. Throughout the district it is natural, almost inevitable, that at the base of the sedimentary series there should have been deposited a conglomerate quartzite. It is therefore not impossible, indeed it is probable, that the westward part of this belt of quartzite belongs, in age, with the lower part of the Siamo slate, as developed to the east, rather than with the Ajibik quartzite. However, as it constitutes a continuous lithological formation and as there is no basis upon which to make the equation, and as above it there occur the representatives of the Siamo slate, at least as far west as sec. 28, T. 47 N., R. 27 W., the formation is here considered. On account of the resistant character of the quartzite, at various places it becomes one of the chief topographic features of the district. South of the southeast arm of Goose Lake the bold quartzite exposures rise steeply from the lake, and from the sand plain to the east and south. The series of ledges composing the quartzite belt are almost continuous to the westward, everywhere rising abruptly from the valley to the south, and in secs. 27, 28, and 29, T. 47, N., R. 26 W., the quartzite constitutes the Ajibik Hills, a bold east and west ridge, with precipitous, south facing exposures. This ridge rises about 200 feet from the valley of Ajibik Creek. On the north side the ridge falls away less steeply, to the exposures of the Siamo slate. The most detailed topographic map would fail to give an idea of the exceeding roughness of this ridge. While it has the general features above given, in a smaller way it is exceedingly rugged, a north-and-south traverse ascending precipitous bluffs, to almost immediately descend into a steep ravine, the other side of which must be climbed but to repeat the performance. As has been said, in sec. 28 this ridge branches into two parts, one of which swings west about a mile. The main belt swings to the north into sec. 21, T. 47 N., R. 26 W. Here there are again numerous huge exposures of the quartzite. Following along the course of the belt to the northeast, between secs. 22 and 23, there are again numerous large exposures. Continuing to the north, the formation has a position between the Wewe slate and the Siamo slate. The quartzite, being the more resistant rock, occupies the higher lands, between lower lands to the south and to the north. In the valley of Carp River the exposures are, however, less numerous than to the southwest, although sufficiently abundant to show that the belt is practically continuous to sec. 36, T. 48 N., R. 26 W. From this point exposures are not abundant until the quartzite east of Teal Lake is reached, where again the exposures are large. From this place they extend almost continuously along the north side of the quartzite range to sec. 35, T. 48 N., R. 27 W. From here west to Michigamme the exposures are not abundant, but are found at a number of places close to the Archean.

Where the formation appears south of the Negaunee iron formation, in secs. 34 and 35, T. 47 N., R. 26 W., there are exposures of quartzite and conglomerate. West for some distance the topographic features are given by the Archean to the south and the jaspery iron formation to the north, so that the quartzite usually occupies a valley between these two formations, but with frequent exposures in secs. 31, 32, and 33. West of the Volunteer mine the formation appears as a conglomerate below the iron-bearing member. In sec. 30, to the north, there is a number of large and typical exposures. West of this place the quartzite is again in the valley between the Archean to the south and the iron formation to the north, there being only a few exposures. The rock is found facing the granite near the center of sec. 28, T. 47 N., R. 27 W., and somewhat unusual slaty phases, interbedded with amygdaloids, are found near the top of the formation in secs. 27 and 28. Several exposures are found in sec. 19, west of which are no outcrops until the vicinity of Humboldt is reached, where exposures are again found south of the iron formation. The remaining exposures are considered in Chapter IV.

FOLDING.

The topographic features and the exposures are closely dependent upon the folding to which the quartzite has been subjected. (Pls. XIII–XV.) Beginning south of Goose Lake the quartzite constitutes an eastward-plunging anticline over the Wewe slate in sec. 23. To the north this anticline is quickly followed by a syncline, so that the section from north to south includes a southern anticline and a northern syncline. Following the belt westward, the formation constitutes the southward slope of an anticline, the crown of which is to the north in the area of the Wewe slates and Archean islands. The belt is continuous to sec. 28, T. 47 N., R. 26 W., where, still constituting one side of an anticline, it swings northwest, and then north. The westward projecting arm, which runs into the NW. ¼ sec. 28 and the NE. ¼ sec. 29, is due to a subordinate anticline which springs up on the slope of the main anticline. The greater breadth of the formation in sec. 28 is due to this same cause. The westward projecting arm is a westward-plunging anticline, so that the quartzite soon disappears under higher formations. In the center of this anticline a small area of Archean appears. The main belt of the formation swings to the northward, thence northeast, thence east to Carp River, and thence north and west to Teal

Lake. This main belt is thus a part of the great westward-plunging syncline of the eastern half of the district, dipping to the north along its southern arm, dipping to the south along its northern arm, and dipping to the west at the eastern end of the syncline.

West of Teal Lake, the regularly bedded, typical quartzite, in passing to lower horizons, is found to be somewhat plicated, then more plicated, and finally very closely plicated into a series of minor cross folds, with axes plunging sharply to the south, following the general dip of the formation.

In secs. 30 and 31, T. 48 N., R. 28 W., and in sec. 25, T. 48 N., R. 29 W., the quartzite makes to the north, and here the characteristic folding of the district is well illustrated (Pl. XVIII), the formation being infolded in the most complicated fashion with the granite and gneiss of the Archean, the whole being a set of isoclinal overfolds with southern dips. The fragmental rock occupies the valleys, and the granite the elevations. These valleys open out to the west and close to the east, the granite thus forming amphitheaters about the quartzite. This is due to the fact that the south-dipping isoclinal folds have a steep westward plunge. As a result of this plicated folding, an island of granite appears surrounded by the Ajibik quartzite and within the Siamo slate above the quartzite in sec. 31, and another island of granite occurs within the quartzite in sec. 30. Consequently, while the overfolds have a westward plunge as a whole, there are north-south subordinate rolls, the synclines of which so depress certain parts of the area as to allow the quartzite to cut off islands of granite at the intervening anticlines.

Running southeast in the Archean area of sec. 23 and the Archean area of sec. 22, T. 47 N., R. 26 W., is a northwestward-plunging syncline of the quartzite, making an arm projecting from the main area. This belt may extend farther than mapped and connect with the belt to the south.

With the exception of a single swing about the Archean anticline in sec. 30, T. 47 N., R. 26 W., the southern belt of quartzite has a general northward dip away from the Archean and under the iron formation. The exposures in secs. 27 and 28, T. 47 N., R. 27 W., when cursorily examined appear to have a uniform northward dip, but when closely examined the upper members of the formation, which are here slates, are found to be pressed into a sharp set of overfolds, with northern dips. These folds are not horizontal, but plunge steeply. Accompanying these minor rolls are, doubtless, major rolls. This is indicated by the fact that interstratified with the slate are apparently three belts of amygdaloid; but as the amygdaloid is all exactly alike, and as this rock is absent elsewhere in the formation, it is more than probable that this is the same lava flow, reduplicated by the northward-dipping overfolds. In the Republic tongue and the next tongue to the west, the Ajibik quartzite is in a closely compressed syncline.

PETROGRAPHICAL CHARACTER.

Macroscopical.—The Ajibik quartzite has two main areas; a western one, in which it rests directly upon the Archean, and an eastern one, in which it is underlain by the Wewe slate. As fully treated in another connection, this difference is explained by the transgression of the sea from the east. The Ajibik area in contact with the Archean extends west from the Teal Lake quartzite range on the north, and from sec. 35, T. 47 N., R. 26 W., on the south, to the west end of the area treated. Also there is here included the area in sec. 29, T. 47 N., R. 26 W. The second area comprises the remainder of the formation.

Where the formation rests directly upon the Archean its basal part is a conglomerate or recomposed rock, the material of which is derived mainly from the immediately subjacent formation. In short, the conditions of formation are the same as, and the phases of the basal rock identical with, those of the Mesnard quartzite, described on p. 520. This is entirely natural, as the two are in fact but parts of the first deposit of the transgressing sea. The basal conglomerates, slates, and graywackes for this part of the area quickly grade up into quartzite, which does not differ from that of the remainder of the formation.

In the eastern part of the area, as the Wewe slate passes into the Ajibik quartzite there is usually an intermediate phase, or interstratifications of the two. Often the slate varies into a coarse graywacke, this into a feldspathic quartzite, and this into the ordinary quartzite. In other cases the transition phase is a novaculitic quartzite. With these are sometimes red and brown iron-stained kinds. In places the white and green phases and the ferruginous varieties show the most curiously complex relations, one appearing in the other in the most indiscriminate manner, as if in extremely irregular inclusions or patches. This iron staining is evidently a secondary process, and the differing effects have been produced by the varying depths to which the solutions have penetrated. In one exceptional locality, in sec. 6, T. 47 N., R. 25 W., the basal member of the quartzite is a conglomerate interstratified with slate, the fragments of the conglomerate being mainly from the Wewe slate.

The central part of the formation in its ordinary phases is a rather pure, typical, vitreous quartzite. In some places this quartzite becomes conglomeratic, and bears small pebbles of white quartz or red jasper. In other places it is interstratified with belts of mica-slate or graywacke. In many places the formation has been subjected to dynamic forces. In the weakest phase of alteration the quartzites are simply broken to a greater or lesser degree, and the crevices thus formed have become cemented with finely crystalline cherty quartz, or with oxide of iron, or both. In a further degree of the process the quartzites have been fractured through and through, and in places pass into Reibung's breccias. In the numerous ramifying, branching, and intersecting cracks, silica and iron oxide have infiltrated. The silica in places takes on cherty or jaspery forms, and in other places it has crystallized as a vein quartz. This secondary material may locally be so abundant as to compose a large part of the rock, and sometimes entire specimens, or rarely considerable belts of chert or vein quartz and iron oxide may be obtained. In proportion as the fracturing and secondary cherty silica increase, the rocks assume a peculiar vitreous aspect. The iron oxide has crystallized as hematite and magnetite, the latter now largely changed to martite.

In their very general brecciation, with consequent considerable areas of pseudo-conglomerates, in the secondary veining, both with coarsely and finely crystalline quartz, and in the large quantity of secondary hematite and magnetite which has formed in these quartzites, they differ from the Ishpeming quartzite of the Upper Marquette series. Apparently in some cases the brecciation was produced before the rocks became thoroughly indurated, while the fragments had a sandy matrix, in which case the individual grains were broken asunder, and the whole has been indurated by secondary infiltrating silica and iron oxide. In some localities very peculiar dynamic effects are observable. As a result of the folding a most curious spheroidal fracturing has occurred, resulting in roundish pebble- and bowlder-like forms. Iron oxide has infiltrated along the cracks, and has especially affected the more fractured and broken matrix, so that the spherical pieces appear like pebbles derived from a different rock. In the most extreme phase we appear to have white spheroids of quartzite in an iron-stained quartzite matrix; a close examination shows, however, that many of the supposed pebbles are not entirely surrounded by the matrix, but are really attached at some place to it. Following along the pseudo-conglomerate belt, we pass from this most conglomeratic-looking phase to that in which there is less and less of dynamic action, and the rock by gradation passes into the ordinary quartzite of the area. In the intermediate phase, while conchoidal fractures have occurred, they have not gone far enough to wholly separate the different parts of the rock, so that what would have been separate fragments had the process gone further, are but a half or a third separated from the quartzite background. In the most extreme phase of dynamic effects, instead of the quartzite becoming brecciated, it has been sheared throughout, and it thus passes into a biotitic or muscovitic quartz-schist, or into coarse, completely crystalline, typical chlorite-schists, biotite-schists, and muscovite-schists.

In the northern and eastern part of the district the quartzites grade upward by interstratifications into the Siamo slate. In the southern and southwestern part of the district the formation grades in a similar manner into the nonfragmental Negaunee iron formation; in secs. 27 and 28, T. 47 N., R. 27 W., the intermediate phases are slates like those of the Siamo formation.

Microscopical.—Where the Ajibik quartzite rests upon the Archean, and therefore has a conglomerate or feldspathic quartzite at its base, it is very similar to the basal conglomerates of the Mesnard quartzite and Wewe slate, described on p. 534. In those cases the basal rock is sometimes a distinct conglomerate, and in other cases it is a rock composed mainly of the separate mineral constituents of the adjacent underlying group. As in the case of those formations, frequently the basal horizon has become so much sheared as to pass into a crystalline schist. In these cases, in place of the conglomerate, we have chloritic, sericitic, biotitic, or muscovitic schists, and in the most extreme phase the rocks pass into typical mica-schists, the leaflets of biotite and muscovite being of large size and having a parallel arrangement. In this phase the quartz grains have been wholly granulated, the new quartz which has developed is similar in appearance to these granules, and the original feldspar has wholly decomposed, its place being taken by the muscovite, biotite, and secondary quartz. In certain of the schist-conglomerates, while the matrix is completely crystalline, in hand specimens the sheared and greatly elongated conglomerate pebbles may still be recognized.

When the formation underlying the Ajibik quartzite is the Wewe slate, there is apt to be interlaminated with the lower horizons of the quartzite biotitic and sericitic slates and graywackes, which are in every respect similar to those described (p. 535) under the Wewe formation.

In the purest and least-sheared phase of quartzite the rocks are composed almost wholly of rounded grains of quartz of somewhat uniform size, which are beautifully enlarged, the enlargements filling the entire interspaces. But even in this least-sheared quartzite the grains uniformly show undulatory extinction, and some of them are distinctly fractured. When the dynamic effects are somewhat stronger between and in connection with the enlargements of the quartz grains, there is a fine mosaic of independent interstitial quartz; and with this there is a beginning of the arrangement of the grains with their longer axes in a common direction. Very frequently the fractures of the grains pass directly across the cores and the enlargements, showing that the folding occurred after the second growth of the quartz grains. Occasionally with the simple quartz grains there are finely complex grains of quartz, which appear to be derived from chert. In a phase intermediate between the quartzites and the graywackes there is present with the quartz a greater or lesser amount of kaolin, sericite, and chlorite. In some cases these become rather abundant, so that the rocks are chloritic or sericitic quartzites. Not infrequently the quartzites are feldspathic; and in some cases this mineral has undergone to a greater or lesser degree the usual decomposition into mica and quartz, or into chlorite and quartz. When the decomposition is complete, in place of the round grains of feldspar we have an interlocking mass of sericite and quartz, biotite and quartz, or chlorite and quartz, as the case may be. At one place the feldspar grains are as distinctly enlarged as the quartz grains. These quartzites usually contain a small amount of iron oxide, which marks the cores of the original quartz grains and is intermingled with the new quartz.

In the quartzites where the dynamic forces were stronger the individual grains of quartz are broken apart, or the rock is fractured through and through, or even changed into a Reibung's breccia. In the larger crevices and cracks is vein quartz or iron oxide; sometimes one alone, frequently the two together, although the quartz is more abundant. These veins in some cases are coarsely crystalline quartz; in others they are finely crystalline, cherty, or jaspery quartz, and with these are iron oxides. These ferruginous chert and jasper veins often have the iron oxide and the quartz arranged in bands or irregularly separated, and they are exactly similar to the jaspilite of the Negaunee formation. Often the vein material is mingled with fragmental quartz, the grains having been broken from the rock and fallen in the crevices. When the individual grains of the rock have been sundered, these are cemented by the secondary quartz and iron oxide exactly as are the larger spaces. The recognizable original grains of quartz show strong dynamic effects, all of them showing undulatory extinction, and many of them being broken into several individuals, or even wholly granulated. In some cases the cracks have a parallel arrangement in two directions, at right angles to the major and mean pressures. The areas in which the grains have been rent asunder and those in which they have not are very irregular, and in the field the first are usually separated from the second by stains of iron oxide.

In those cases in which the secondary quartz is abundant, and the primary quartz has been granulated, so that it no longer has a clastic appearance, we have an intricately interlocking mass of quartz grains of various sizes, in which the original material can not be discriminated from that which has come in later. Sometimes the whole rock is composed of small, closely fitting granules of quartz. The granulated material is usually finer or coarser than the interlocking and intersecting veins, and in the latter iron oxide is usually abundant. These rocks, in which the evidence of fragmental origin has disappeared, and yet which do not have a schistose structure, are called quartz rocks. All of these phases are so similar to the jaspilite of the Negaunee formation that the two could not be separated in thin section. However, these extreme phases are traced into those which are less modified, there first appearing a few distinctly clastic grains, then clusters of them, until we have an intermediate variety, in which perhaps half of the section shows fragmental quartz buried in a crystalline matrix.

Resulting from the differing modifications of the original sandstone, we therefore have in the area quartzite, cherty quartzite, ferruginous quartzite, ferruginous cherty quartzite, quartz-rocks, quartzite breccia, vein quartz, vein chert and jasper, and other phases.

The rather peculiar autoclastic rocks, which resemble quartzite conglomerates, were mentioned in the macroscopical description. The pebble-like areas, which were believed to be due to spheroidal fracturing, are clearly shown to be of this character in the thin section. Instead of having smooth exterior boundaries, as would be expected in water-worn pebbles, there are minute irregularities, such as would be produced in fracturing. These spheroidal, pebble-like areas are found to be pure vitreous quartzites, which are wholly cemented by the enlargement process, or, more rarely, by this combined with finely crystalline, interstitial quartz. These pebble-like areas rest in a background composed of quartz grains, which are set in a matrix composed of finely crystalline quartz, iron oxide, and sericite. It is apparent that the individual grains of this part of the rock have been broken apart, and thus have allowed these secondary materials to enter, whereas in the uncrushed, pebble-like areas there has been no or very little room for them. It is clear that before this rock was brecciated it was indurated to a quartzite by the enlargement process.

In the macroscopical description a locality was mentioned where the lowest formation of the Ajibik quartzite appears to bear slate fragments. Here its lowest horizon consists of interstratified slates, graywackes, and conglomerates, which quickly pass up into ferruginous quartzite, and this into the ordinary vitreous rock. The slates consist of interstratified coarse and fine materials, which differ chiefly from each other in that the coarser layers contain numerous large fragmental grains of quartz, usually simply, but sometimes coarsely complex, and sometimes cherty. The matrix is clayey material, so fine that it is difficult to determine the constituents, but sericite, quartz, chlorite, feldspar, and ferrite are present. The conglomeratic layers also bear fragments of the underlying Wewe slate. However, these fragments when closely examined are not sharply outlined, as is usual with ordinary fragments, but are greatly elongated, and have minutely irregular borders, the projections of which fill the interspaces of the quartz grains. This suggests that the underlying slate was not indurated at the time it yielded the fragments to the quartzite, being rather a compacted clay than a solid rock.

For those parts of the area where the Ajibik formation is overlain by the Negaunee iron formation the lower grades into the higher, or beds which belong lithologically in the two formations are interstratified. In passing from the lower to the higher formation, when the lowest rock of the Negaunee formation is jasper, the change takes place by the dying out of fragmental quartz and the appearance of hematite, magnetite, and finely crystalline quartz. When the overlying formation is actinolite-magnetite-schist, the minerals which appear are magnetite, actinolite, and often garnet. Occasionally the intermediate phase is a ferruginous slate, like the transition horizon of the Siamo and Negaunee formations. In the southwest part of the area—that is, in the

Republic and Southwest tongues—the folding and consequent shearing have been so severe as to transform the Ajibik quartzite formation into a completely crystalline schist. Even the most quartzite phases now show no distinctly fragmental grains of quartz, but consist of coarsely crystalline interlocking quartz, between and in which are small amounts of actinolite, garnet, chlorite, biotite, and muscovite. In some cases the chlorite has developed from the actinolite and garnet. While the quartz grains show undulatory extinction and fracturing, the dynamic effects are not so great as would be expected, and the appearance of the section strongly suggests that the rock is largely recrystallized. Where the sandstones were less pure there have developed from them coarse-grained, typical biotite-schists, muscovite-schists, and chlorite-schists, often garnetiferous. In these rocks we have a somewhat uniformly granular quartzose background, between and through which have developed the biotite, muscovite, and chlorite. There is a tendency for the micaceous minerals to be concentrated into layers, the less micaceous zones perhaps corresponding to the original, more quartzitic laminæ. Occasionally the quartzose bands have a distinct oval or lenticular character, as if each represented a greatly sheared and granulated quartz pebble. The mica wraps and bends around these areas, joining at their ends, and thus presenting a mesh-like appearance, the holes of the meshes being represented by the quartz areas, and the whole simulating somewhat a diagonally stretched net. In some of the slides the biotite, muscovite, and chlorite are all in large blades with a parallel arrangement. In other cases the sericite is in part in innumerable minute leaflets. In certain of the chlorite-schists the chlorite leaflets are minutely puckered by the folding in certain places, and in other places the stress has been relieved by minute faulting, diagonal to the schistosity. Thus we have a cleavage in two directions, one parallel to the schistosity and the other diagonal to this, the latter being a fault-slip cleavage. By a dying out of the micaceous element and the appearance of actinolite and magnetite these schists pass into the Negaunee formation. In some cases there are interstratified, typical, biotite-schists, and actinolite-magnetite-schists. These biotite-schists are usually, however, strongly garnetiferous. The garnet, as usual, has developed in large individuals, which include very numerous granules of quartz. Where the garnet appears the biotite is absent, so that we have a ramifying background of biotite and quartz, in which are large garnet individuals, including quartz and a small amount of biotite. In the schist conglomerate south of Republic the matrix is a completely crystalline mica-schist, and in their shapes and relations to the matrix the sheared-granite pebbles are similar to the quartz areas just described.

RELATIONS TO ADJACENT FORMATIONS.

For the part of the belt running from Goose Lake to near Teal Lake, the quartzite occupies a place between two slates. It was suggested that the mud of the Wewe slate began to deposit because by the upward building of the limestone the waters became too shallow for limestone building. A continued shallowing of the water may have gone on by the upbuilding of the slate, until it became so shallow as to permit the waves to carry coarse-grained sand, when the sandstone was deposited, which was indurated later into the Ajibik quartzite. In places it may be that local elevations occurred, raising the mud above the water, so that when the waves next overrode it, it yielded fragments of compacted mud to the basal horizon of the quartzite. This is indicated by the fact—discovered by Mr. Seaman—that in sec. 6, T. 47 N., R. 25 W., south of Carp River, the quartzite, with a conglomerate at its base containing slate fragments, rests with slight discordance upon the slate. Also interstratified with the quartzite for a few feet from the base are thin belts of conglomerate, bearing fragments of slate identical in character with the slate below. To account for the full thickness of the sandstone, it is supposed that subsidence, if interrupted at all, soon began again. After a time it appears that the rate of subsidence was greater than the rate of upbuilding, so that following the sand deposits there was another time of mud deposits. Further indicating such a subsidence is the fact that above this shale followed the nonfragmental iron-bearing formation. In the eastern part of the area the quartzite grades above into a shale, and below it rests upon the shale.

In the area west of Goose Lake the Wewe slate, as has been said, appears to grade up into the Ajibik quartzite, in many places the boundary line between the two being somewhat arbitrarily placed.

In the quartzite range in sec. 29, T. 47 N., R. 26 W., the quartzite rests immediately upon the Archean, the Wewe slate not appearing between the two, as is the case to the eastward. This is explained by the fact that the transgression of the sea is from the east, but it is not impossible that the lower part of the quartzite is really the equivalent of the upper part of the Wewe slate, sand being deposited near shore at the same time that mud was being deposited offshore.

East of Teal Lake, supposing the slate belt in the middle of the quartzite to belong with the Wewe slate, there is a transition from the slate upward into the quartzite. West of Teal Lake it has been seen that the inferior formations of the Lower Marquette series are not deposited, and therefore that the quartzites rest directly upon the Archean. In the petrographical description it has been indicated that here basal conglomerates occur. Just north of the west end of Teal Lake, and at various places for a few miles west, the actual contact between the quartzite and the green schists, greenstone-conglomerates, and amygdaloids of the Archean are found. One of the best localities at which to observe this contact is just north of the west arm of Teal Lake. Here the green schist strikes approximately east and west, and its schistose structure dips at a high angle—75° to 80°—to the south. However, the contact of the quartzite and schist dips but 55° to the south, so that the fibers of the schist abut against the contact plane at an acute angle (fig. 15). Above the contact plane is a genuine basal conglomerate, the fragments of which are mainly derived from the schist, and with which are also large fragments of quartz, some of them 8 or 9 inches in greatest diameter. Besides the green schist and quartzite pebbles, there are also present abundant fragments of a more acid schist, which is like the acidic schists occurring in the Northern Complex, north of the stone quarry at Carp River. There can be no doubt that here the green schist had become foliated and was deeply truncated before the deposition of the overlying conglomerate.

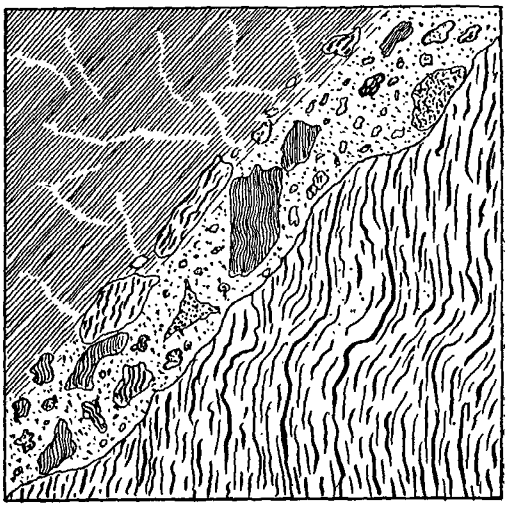


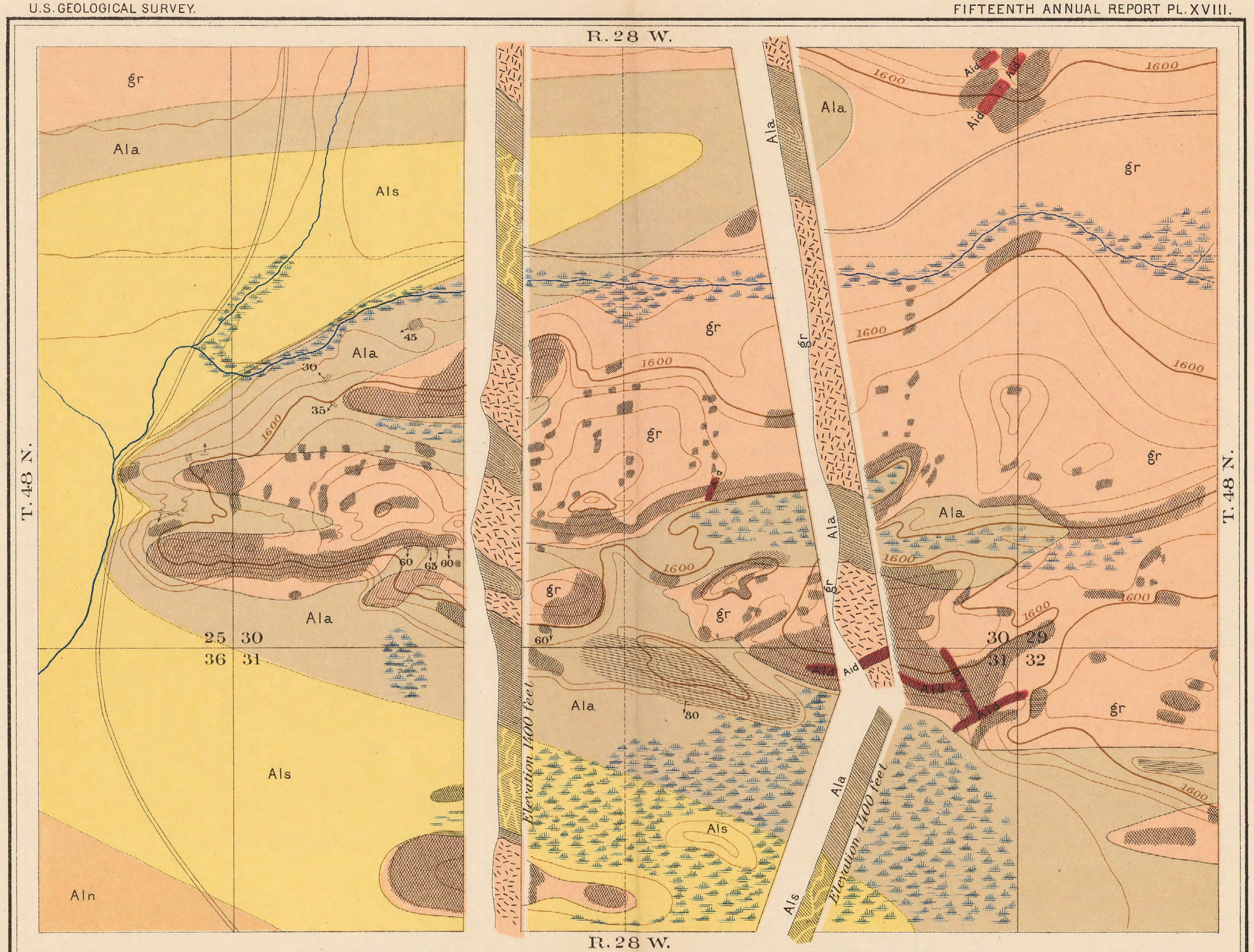
Fig. 15.—Ishpeming quartzite resting uncomformably upon Kitchi schist.

At several localities for a half mile west of Carp River, there are also found between the quartzite and contacts green schist. The quartzite near the contact is intensely plicated, but wherever an opportunity could be found to get at the contact a sharp one between the two rocks was invariably discovered. In only one case was the plicated quartzite found in any other position than on the south slope of the schist. Here it wraps around the east end of a small knob of schist, and is found on the north side with its typical characters. This occurrence is probably explained by regarding the green schist knob as a headland projecting somewhat diagonally off from the old shore-line, and therefore giving a bay in which the detrital material could be deposited behind the schistose rock. When the two were later upturned to their present inclination, the tilting would result in the present distribution.

At various localities east of Teal Lake the lowest quartzite is found to be in contact with the green schist. This may be particularly well seen just west of the road running north from Negaunee, and east of the gorge of the Carp River. The relations are, however, essentially the same as west of Teal Lake, with the exception that east of Carp River there has been such intense shearing and accommodation near the contact plane that the basal rock has become a schist-conglomerate, which closely resemble the much-sheared green schist of the Northern Complex. It is difficult to say exactly where the green schist ends and the schist-conglomerate begins. In discriminating between the fragmental and crystalline rocks the microscope is frequently of considerable assistance. The igneous character of the green schist in its typical form is plain, while the fragmental character of the quartzite is equally evident; but close to this contact even the microscope fails to discriminate between the igneous rocks and the intensely sheared, metamorphosed, and recomposed fragmental rocks. We have, then, an apparent transition between the green schists and the fragmental rocks just above, as we have an apparent gradation between the Mesnard quartzite and the granite-gneiss south of Marquette. In both cases, however, the conglomerates along the contact, in areas in which dynamic action has not been so severe, reveal the true nature of the relation, and show that the downward gradation is secondary, and is not evidence of a single continuous series with downward progressing metamorphism.

These contacts east of Teal Lake may belong rather at the base of the Mesnard quartzite than at the base of the Ajibik quartzite, as has been explained above, but the connection between them and the contacts west of Teal Lake are so close that their description was deferred to this place. Wherever their correlative position, all of the contacts along this belt of conglomerate mark the advance of a shore-line, encroaching from the east toward the west.

The intricate structural relations which obtain between the quartzite and granite in secs. 30 and 31, T. 48 N., R. 28 W., and in sec. 25, T. 48 N., R. 29 W., have already been described. Here, along the complex dividing line, the contacts between the two rocks are found at numerous localities. In many cases the lowest horizon of the quartzite is strongly conglomeratic, the fragments of the conglomerate being mainly derived from the immediately subjacent granite. These conglomerates at the contacts, the positions of which are indicated on Pl. XVIII, show conclusively that the granite is older than the quartzite and was deeply denuded before the deposition of the latter formation. However, at many places so close has been the folding, and so intense the shearing and accommodation along the contact plane, that the quartzite becomes a quartz-schist, closely resembling the sheared granite. Further, the secondary schistose structure in the granite and that in the quartzite are parallel, and this structure is particularly prominent just at the contact of the two rocks. Here again, if one considered only certain localities, the phenomenon might be regarded as an indication of the downward gradation by progressive metamorphism of the quartzite into the granite, or the explanation might be given that the granite is intrusive within the quartzite. However, if the contact be followed throughout its various windings, and the phenomena carefully studied, the only conclusion which can be reached is that the quartzite is a newer formation which has derived its detritus in largest measure from the underlying formation. West of sec. 25 no contacts between the granite and quartzite have been discovered, but the latter near the granite frequently becomes feldspathic in character, indicating the derivation of its material largely from the subjacent granite.



GEOLOGICAL MAP OF AREA NORTH OF CLARKSBURG

DIABASE	LOWER MARQUETTE: NEGAUNEE FORMATION	LOWER MARQUETTE: SIAMO SLATE	LOWER MARQUETTE: AJIBIK QUARTZITE	ARCHEAN: GRANITE	OUTCROPS: OBSERVED MASSIVE ROCKS	OUTCROPS: OBSERVED BEDDED ROCKS
Aid	Aln	Als	Ala	gr		

SCALE

0 — 1/8 — 1/2 MILE

CONTOUR INTERVAL 20 FEET

The southern belt of the Ajibik quartzite rests unconformably upon the Archean south of the Cascade Range, as shown by the presence of great basal conglomerates, the bowlders of which are derived from the immediately subjacent iron formation. No actual contacts are here found, but, as first observed by Dr. Wadsworth, the great conglomerate adjacent to the Platt mine, sec. 32, T. 47 N., R. 26 W., containing fragments of granite, basic eruptive rocks, and schists, each identical with the corresponding kind of rock in the Archean to the south, proves the existence of this unconformity. Exactly similar phenomena are found in sec. 34, and here the interval separating the basal conglomerate and granite is but a few paces. In sec. 28, T. 47 N., R. 27 W., the shearing action seems to have been so powerful that the conglomeratic quartzite which here occurs has been changed to a schist. At the Cascade Range the quartzite grades above by interstratification into the Negaunee iron formation. In some cases there are a number of interlaminations of the pure jasper and almost pure quartzite. However, upon the whole, in passing upward the belts of quartzite become less and less numerous and thinner, until they finally disappear.

The contact phenomena of the Lower Marquette series and the Archean shown at various localities strongly suggest that in many cases which have been explained as downward metamorphism of a sedimentary into a completely crystalline rock, or as a sedimentary rock intruded by granite, the phenomena may have another explanation. If the metamorphism of the Marquette district had been so severe as to have wholly obliterated the conglomerates which occur at various places, it would have been almost impossible to show that between the Lower Marquette series and the Archean there is a great unconformity.

THICKNESS.

As in the case of the previous formations, it is exceedingly difficult to give any accurate estimate of the thickness of the Ajibik quartzite. As the folding is very complex west of Goose Lake, where the most continuous exposures are, any computation based upon the breadth of outcrop and average dip would be sure to give conclusions far from the truth. In the belt extending north and east from this area there are no continuous exposures, with well-determined dips, for the entire breadth of the formation. South of Carp River, in secs. 6 and 7, T. 47 N., R. 25 W., there is, perhaps, the best opportunity to make an approximate estimate. Here the breadth of the formation appears to be about 1,200 or 1,300 feet. This, with a dip of 35°, would give a thickness of about 700 to 750 feet. East of Teal Lake it is perhaps possible to give the maximum thickness of the slate and quartzite from the base upward, but how much of these exposures belongs with the lower formations it is, as has been said, impossible to state. If the slate included with the

Goose Lake slate is correctly placed, above this is a breadth of quartzite of 1,000 feet, which with an average dip of 65°, gives a thickness of about 900 feet.

SECTION V. THE SIAMO SLATE.

The Siamo slate is so called because abundant exposures occur between the Ajibik quartzite and the Negaunee formation on Siamo Hill just south of the west part of Teal Lake, and because the most typical rock of the formation is a slate, although locally it passes into a graywacke, and often into a rock approaching a quartzite.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Beginning at the north and west, the first exposures of this rock occur between the Ajibik quartzite and the Negaunee formation north of the Michigamme mine. From this place the formation stretches in a general easterly course for a number of miles to sec. 35, T. 48 N., R. 26 W., east of Teal Lake. East of sec. 33 is a broad area of the formation, extending to sec. 5, T. 47 N., R. 25 W., the slate being the topmost member of the great westward-plunging syncline. On the south side of this area the formation divides into two parts. The eastern arm swings to the south and southwest past the northwest arm of Goose Lake; thence west, southwest, and south to sec. 29, T. 47 N., R. 26 W.; thence south about the west end of the anticline made by the Ajibik quartzite; and thence east to the sand plain in sec. 24, T. 47 N., R. 26 W. The western area extends west through sec. 3, and in secs. 4, 5, 8, and 9, T. 47 N., R. 26 W., constitutes a broad dome with minor folds. From sec. 9 an arm extends southwest, terminating as a plunging anticlinal dome in sec. 20. Farther southwest, in secs. 19 and 30, is another area which was probably originally continuous with the area in sec. 20.

The slate, being a soft formation, is not as a whole well exposed, but sometimes it becomes a mica-slate or a coarse graywacke, when the exposures are more numerous. Upon the whole, however, the formation occupies the lowlands between the more resistant Ajibik quartzite and the Negaunee formation. North of the Michigamme mine there are a number of exposures; from this place until Teal Lake is reached there are few. However, south of the west arm of Teal Lake is Siamo Hill, which gives the name to the formation and upon which exposures are numerous. The iron formation is here soft, and occupies even lower ground than the slate. East of Teal Lake there are many exposures of the formation south of the quartzite range. These exposures become more and more sparse in passing east, but they are still frequent to sec. 35, T. 48 N., R. 26 W. From this place there are no more natural exposures until we get south of the Carp River, where again a number of exposures occur, but with long intervals between them. As the belt swings to the west, following the northern arm, the exposures in secs. 3, 4, 5, 8, and 9, T. 47 N., R. 26 W., are very numerous. The formation here contains much graywacke, and is therefore more resistant, and we have a rough but elevated area surrounded by the less resistant iron formation. In the southwesterly extension of the belt prominent exposures occur in the center of sec. 20. In the arm which swings southwesterly from sec. 2 around the Ajibik quartzite to the sand plain, the exposures are few, and the land occupied by the belt is low. In secs. 19 and 30 there are numerous exposures, and the area as a whole is one of elevation.

FOLDING.

Beginning with the formation at the west the northern belt has, upon the whole, a southern dip. However, when the exposures are examined in detail, it is found that the rocks are in a set of minor rolls, the dips sometimes being to the north, sometimes to the south. The latter are more persistent because of the general south dip of the formation, and therefore more conspicuous (fig. 16). Also, in places where the folds are overturned, the horizontal or northern dips upon the tops of the anticlines and the bottoms of the synclines turn so quickly in the general southwest direction as to be easily overlooked. This is especially

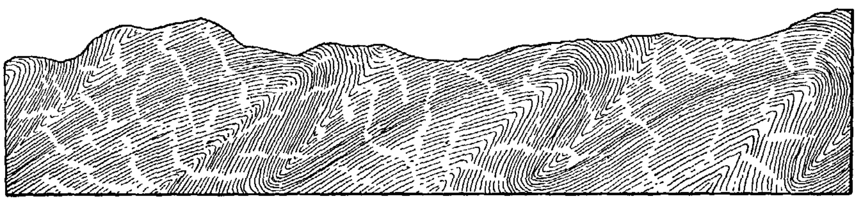


FIG. 16.—Minor overturned folds in Siamo slate.

true if there is a schistosity parallel to the prevalent dips (fig. 17). To the subordinate folding is doubtless due the very greatly varying width of the formation. These minor rolls may be particularly well seen south of the west end of Teal Lake. The broad eastern area is a gentle westward-plunging syncline with minor folds. In the eastern branch which swings to the south in sec. 2, T. 47 N., R. 26 W., the dips are always away from the Ajibik quartzite and under the Negaunee formation. Following the main belt, from sec. 3, T. 47 N., R. 26 W., into secs. 4, 5, 8, and 9 the slates, upon the whole, constitute a great anticlinal dome. There is, however, much subordinate folding, the pressure being more severe in a north-south than in an east-west direction, so that on the northern side of the area the dips are, upon the whole, to the north, and upon the southern side to the south. This, however, is by no means a simple fold, but an anticlinorium with a large number of minor rolls with east-west axes. The north-south major fold causes these minor folds to plunge under the iron formation to the west, and the contact line between the formations curves in a number of reentrants and salients. The salients correspond to anticlines, the reentrants to synclines. The same thing is probably true upon the east side of the area, but here a swamp prevents a close delimitation of the Siamo slate and the Negaunee formation. Following the belt to the southwest, the southwestern termination of the fold occurs in sec. 20, where the iron formation appears in a semicircular belt about the plunging anticline.

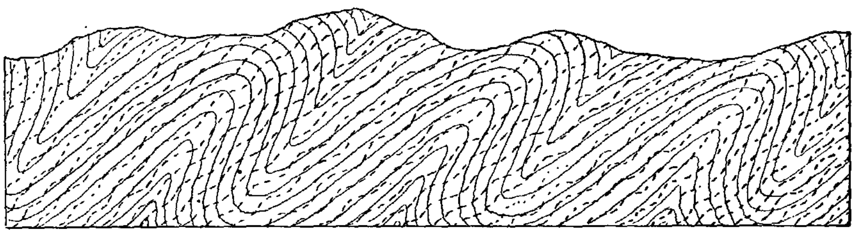


FIG. 17.—Relations of schistosity and bedding in Siamo slate.

This anticline, thus plunging beneath the iron formation, reappears as another anticlinal dome in secs. 19 and 30, T. 47 N., R. 26 W. On a smaller scale, the phenomena are here the same as in the large exposures of this formation to the northeast.

PETROGRAPHICAL CHARACTER.

Macroscopical.—The Siamo slate varies from a coarse-grained feldspathic graywacke approaching a quartzite, through typical massive graywacke, to a very fine-grained slaty rock. The slate and fine-grained graywackes are more abundant than the coarse, feldspathic graywackes.

The finer-grained phases are very generally affected by a slaty cleavage, which often approximately corresponds with the bedding, but which also cuts across the bedding in many places at various angles. As explained on a previous page, the slate in many places is folded into a series of minor, isoclinal folds. The slaty cleavage very often corresponds with the longer axes of these folds, and cuts across the bedding of the shorter legs. Nowhere is the slaty cleavage so regular as to furnish roofing slates. In some cases there has been so much movement along the cleavage planes or between the beds as to develop distinct slickensides, the rock parting into irregular blocks parallel to the bedding and to the cleavage, and each block being smoothed, both parallel to the bedding and to the cleavage, by shearing. In the most extreme phase of alteration the rock is a crystalline mica-schist, with well-developed mica folia. In proportion as the rocks become coarse-grained, slaty cleavage has not developed in them, and it is entirely absent in the coarser-grained graywackes. In general, the rocks of the formation have yielded to the forces to which they have been subjected by folding and shearing, but occasionally the coarser phases are brecciated, and rarely they become Reibung's breccias. This indicates that the formation is more plastic than the other Lower Marquette formations, in which autoclastic rocks are very common.

The normal varieties of the formation are not heavily ferruginous, but in the upper and lower horizons they contain a good deal of iron oxide, and locally interlaminated layers of chert and ferruginous chert, or even actinolitic schists. The contact plane between the Siamo slate and the Ajibik formation seems to have been one of the major planes of movement, and thus numerous cracks and crevices have formed, which have been taken advantage of by iron-bearing solutions from above. The concentration of these ferruginous masses here, although occurring on a comparatively small scale, is analogous to the concentration of the ore bodies on impervious basements in pitching troughs, as explained in Section VI. At the upper horizon the slate changes by gradation or by interlamination into rocks belonging to the Negaunee formation. The ferruginous phases are usually hematitic or magnetitic slates, but occasionally interlaminated or intermingled with the slates are layers of chert or ferruginous chert, which are identical with the similar rocks of the iron formation. In color the nonferruginous varieties of the rocks are usually gray or greenish-gray, but some of the coarser kinds are light gray. In these the naked eye distinctly sees the well-rounded grains of quartz and feldspar. Also, in many of them there appear to be large fragmental grains of mica. In general, the iron oxide staining the slates is hematite, but in some cases it is magnetite. The fine and coarse varieties of the rock are frequently interlaminated, a layer of coarse graywacke being between two fine-grained, slaty layers, and these bands being again composed of still finer bands of different degrees of coarseness.

Microscopical.—The least altered and coarsest graywackes are composed mainly of large, well-rounded grains of quartz, a few of them finely crystalline and cherty looking, and feldspar, between which is a sparse matrix consisting of chlorite, biotite, muscovite, finely crystalline quartz, and more or less ferrite. Usually the chlorite is predominant. but in some cases the biotite and muscovite are equally abundant, Frequently the quartz grains are distinctly enlarged. In most cases they show pressure effects by undulatory extinction and fracturing, the latter sometimes being in a rectangular system. The feldspar grains comprise orthoclase, microcline, and plagioclase. They show beautifully their metasomatic change into chlorite and quartz, biotite and quartz, or muscovite and quartz. In any one case the alteration of individual grains may be into one of these micaceous minerals, more frequently chlorite than any other; very frequently the alteration is into chlorite and biotite, and in other cases into biotite and sericite, although chlorite may also be a simultaneous product. All stages of the change may be seen, from those cases where the outer borders of the feldspar grains are surrounded by a film of the micaceous mineral, through those in which the grains are interlocking masses of the micaceous minerals, quartz, and feldspar, to those where the feldspar grains have entirely disappeared, their places being taken by a roundish, complex mass of the secondary materials. This alteration of the large feldspar grains is so general that it strongly suggests that the most of the chlorite, biotite, and sericite in the matrix has developed from a feldspathic background.

In the least-sheared phases of the graywackes there appears to be no arrangement of the secondary leaflets of chlorite, muscovite, and sericite in any definite direction. Where the dynamic effects have been somewhat greater there is a suggestion of the arrangement of the leaflets of these minerals in a parallel direction; at the same time the original grains of quartz and feldspar have been somewhat rotated, so as to have a similar arrangement. At the same time, too, finely crystalline secondary quartz begins to appear prominently in the background, the quartz grains are somewhat more fractured, and chlorite, which was predominant in the less sheared phases, becomes less prominent, being replaced by biotite and sericite or muscovite. As the dynamic effects become somewhat more severe the slides show distinct evidence of minor fault-slipping parallel to the schistosity, the somewhat irregular, connecting, and mesh-like, although approximately parallel slip-planes being marked by continuous bands of chlorite and mica, mingled with oxide of iron.

The chloritic and micaceous slates differ from the graywackes only in that the distinctly recognizable fragmental quartz and feldspar are much less abundant and the matrix much more abundant. As the quartz and feldspar grains become of very small size they are less rounded, apparently being below the limit of magnitude affected by water action. Out of the feldspar there have formed chlorite, biotite, sericite, muscovite, and quartz, exactly as in the graywackes, and the same minerals have also developed in the matrix. On account of the more plastic character of these rocks the evidence of interior movement is much greater than in the graywackes, the slip-planes being more numerous and approximately parallel, although intertwining.

In a more advanced stage of alteration the slip-planes increase in number and are more nearly parallel, until there are several or many in the breadth of a single millimeter, and here we have typical fault-slip cleavage. The chlorite and mica are arranged, or have developed, parallel to this cleavage. The slip-cleavage very often corresponds with bedding. It appears as though different layers had been pushed forward over one another, somewhat as are particles of dough under the roller, the elongation being greater in the direction of the movement of the roller and less at right angles to this, but in the plane of movement. Sometimes there are present large flakes of mica or of chlorite, which are often bent or contorted, but these appear to be fragmental.

In a still more advanced stage of metamorphism the larger quartz grains are partly granulated, secondary quartz enters, the whole of the feldspar has decomposed, and we have a fine-grained mica-slate. Oftentimes these mica-slates are interlaminated with coarser-grained layers, which distinctly show the clastic origin of the rock. In a single section there may be a number of alternations of mica-slate and micaceous graywacke. Sometimes the fault-slip cleavage is well developed in the mica-slate, and abuts diagonally against the laminæ of graywacke, being less prominent or dying out altogether. In the most extreme phase of metamorphism the coarse, fragmental grains of quartz, if there were any, have become granulated, and the secondary quartz is as coarsely crystalline as this original quartz. The grains of varying sizes fit closely or interlock. The mica and chlorite are in well-developed, parallel blades of considerable size, and thus the rock is a mica-schist. In one phase of the mica-schist are numerous large crystals of chlorite, which have their cleavage transverse to the schistosity. They include numerous grains of quartz. These have probably developed under static conditions after the dynamic movements had ceased. In some of the mica-schists is a considerable amount of clear feldspar, which looks as though it were perhaps in part a secondary development, and thus the rock approaches a mica-gneiss. Although the Siamo formation thus locally becomes a completely crystalline schist, in that it no longer shows in itself any distinct evidence of original fragmental character, the gradation phases enable one to determine its manner of development as above given.

As the slates and graywackes pass into the ferruginous varieties there appears in the matrix more and more of iron oxide, generally hematite, but in many cases magnetite also. These increase in quantity until there are more or less continuous, nearly solid layers of iron oxide, and in the extreme phase of ferrugination the matrix is so heavily iron-stained that little else can be discriminated. When the iron oxide is magnetite, this is apt to take definite crystal outlines. In most cases it is plain that the oxides of iron are secondary infiltrations, being in the matrix, and oftentimes in the enlarged borders of the quartz grains. These ferruginous slates have interlaminated layers of material, which in all respects, except that an occasional fragmental grain of quartz may be seen, are like the ferruginous and sideritic slates and cherts and actinolite-magnetite-schists of the Negaunee iron formation. These are subsequently described in connection with that formation. Often the ferruginous cherty belts cut across the fragmental layers in a minor way, so as to show that they are certainly a secondary product, which has formed approximately parallel to the bedding either by the alteration or replacement of some original constituent or along cracks which have formed as a consequence of dynamic movements, or the two combined. Many of these belts are replacements of original sideritic layers, which were interlaminated with the fragmental sediments at the basal and topmost horizons. From the siderite the other minerals have developed, just as in the Negaunee formation. In other cases the ferruginous and cherty materials which have filled the cracks formed by the folding are probably from an extraneous source.

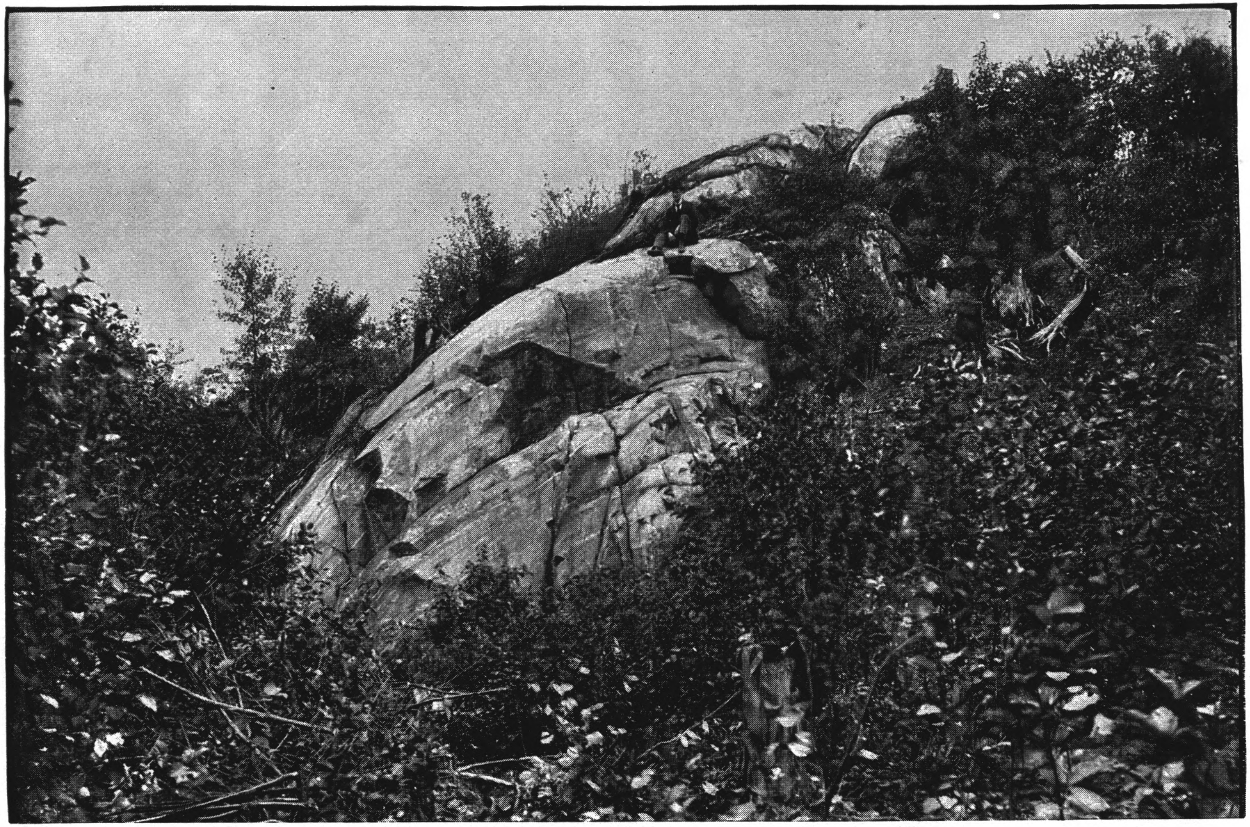
RELATIONS TO ADJACENT FORMATIONS.

It has already been said that the Ajibik quartzite grades upward into the Siamo slate. The transition rocks are usually feldspathic quartzites and graywackes. The best locality at which to observe all the phases of this gradation is east of Teal Lake, in sec. 32. Usually there are no conspicuous exposures which show the exact manner of transition.

Above, the slate is overlain conformably by the Negaunee iron formation. In many places the transition is gradual; in others, rather abrupt. Near the center of sec. 20, T. 47 N., R. 26 W., the formation becomes a coarse graywacke, and even approaches a quartzite, which grades upward into the iron-bearing formation. There are various interlaminations of fragmental and nonfragmental material, until finally the latter becomes predominant. Within this gradation zone the slate contains more or less of nonfragmental material, and after the iron formation becomes practically continuous it includes some fragmental material. The interlaminated beds are here closely infolded, and consequently brecciation and minor faulting have occurred. As a result blocks of Negaunee jasper are found in the graywacke. At one place the lamination of the jasper abuts against the bedding of the graywacke. In sec. 35, T. 48 N., R. 27 W., south of the west arm of Teal Lake, the change is somewhat more abrupt Here the top of the slate seems to have been a shear zone, and the iron-stained slate has become semicrystalline. Resting upon this, with scarcely any gradation zone, are the iron-ore deposits. The above localities are the best found for showing the transition zone. For most of the district exposures are not found along the contact zone between the Siamo slate and the Negaunee iron formation.

THICKNESS.

To give an estimate of the thickness of the previous formations has been difficult, and to determine the thickness of the Siamo slate is even more difficult, because of the intense minor plications to which it has been subjected. In the broad area of Siamo slate in secs. 3, 4, 5, 8, and 9, T. 47 N., R. 26 W., the folding is so complicated that it is impossible to make any estimate of the thickness. The area perhaps most favorable is that adjacent to Teal Lake, where the belt has a width varying from a quarter of a mile to a half mile, or even more. This great variation in width is undoubtedly due to minor rolls in the formation, and taking the narrowest width, 1,300 feet, with a dip of 75°, we would have a thickness of about 1,250 feet. However, it is known that slaty cleavage and surbordinate rolls are developed here, so that it is probable that this thickness should be reduced by one half, and perhaps by more. At the east end of the westward-plunging syncline in sec. 6, T. 47 N., R. 25 W., the slate has a breadth of no more than 200 feet, which, as the dip is almost vertical, gives about the same



QUAQUAVERSAL DOME STRUCTURE OF ACTINOLITE-MAGNETITE-SCHIST, CAUSED BY LACCOLITIC INTRUSIVES.

thickness. The exceptional narrowness of this area may be due to the fact that the slate was not here originally so thick as to the west, or it may be that the apparently much greater thickness of the formation farther west is largely due to the numerous reduplications by the minor folding.

SECTION VI. THE NEGAUNEE FORMATION.

The Lower Marquette iron-bearing formation is given the distinctive name Negaunee because in this town and to the southward are extensive typical exposures of the formation. It is called the iron-bearing formation because within it occur many of the Marquette iron-ore deposits.

RELATIONS TO ERUPTIVES

Vast quantities of greenstone are associated with the iron-bearing formation. This greenstone includes both intrusives and extrusives, the former being much the more abundant. The intrusive rocks are diabase or diorite. The most conspicuous of these intrusives are in the form of bosses, varying from those of small size to those 2 miles or more long and a half mile wide. The bosses are of exceedingly irregular shapes, and from them radiate numerous dikes, varying from small ones to those many feet in diameter. These dikes usually do not outcrop, but mining shows that they frequently connect one boss with another, and thus unite into one mass several apparently detached areas of greenstone. In many cases the greenstone has intruded the sedimentary series in a laccolitic fashion, so that the iron formation has a quaquaversal dip about the greenstone masses. (Pl. XIX.) Quite as frequently the greenstone breaks across the iron formation, when the latter beds may dip against the greenstone. These intrusives particularly affect the iron formation. The bosses of this rock found in the underlying and overlying formations are relatively few and of smaller size. This is so strongly the case that a map of the greenstone areas about Ishpeming and Negaunee is approximately a map of the distribution of the iron-bearing formation. Large and abundant masses of intrusives are also found in the central-eastern arm of the iron formation, are very conspicuous in the masses of actinolite-magnetite-schist constituting Mount Humboldt, and are abundant in the great outcrops of iron formation at Republic and at Michigamme. At the latter place fragments of the Negaunee formation are included within the intrusives (Pl. XX.) While this general relation is very marked, the bosses of greenstone not infrequently penetrate the superior formation (Pl. XXI), and are also found in the inferior formation. A possible explanation of this relation between the intrusives and the iron formation may lie in the exceeding brittleness of the latter. When the series was folded this formation was fractured at innumerable places, thus allowing the wedges of igneous material to enter.

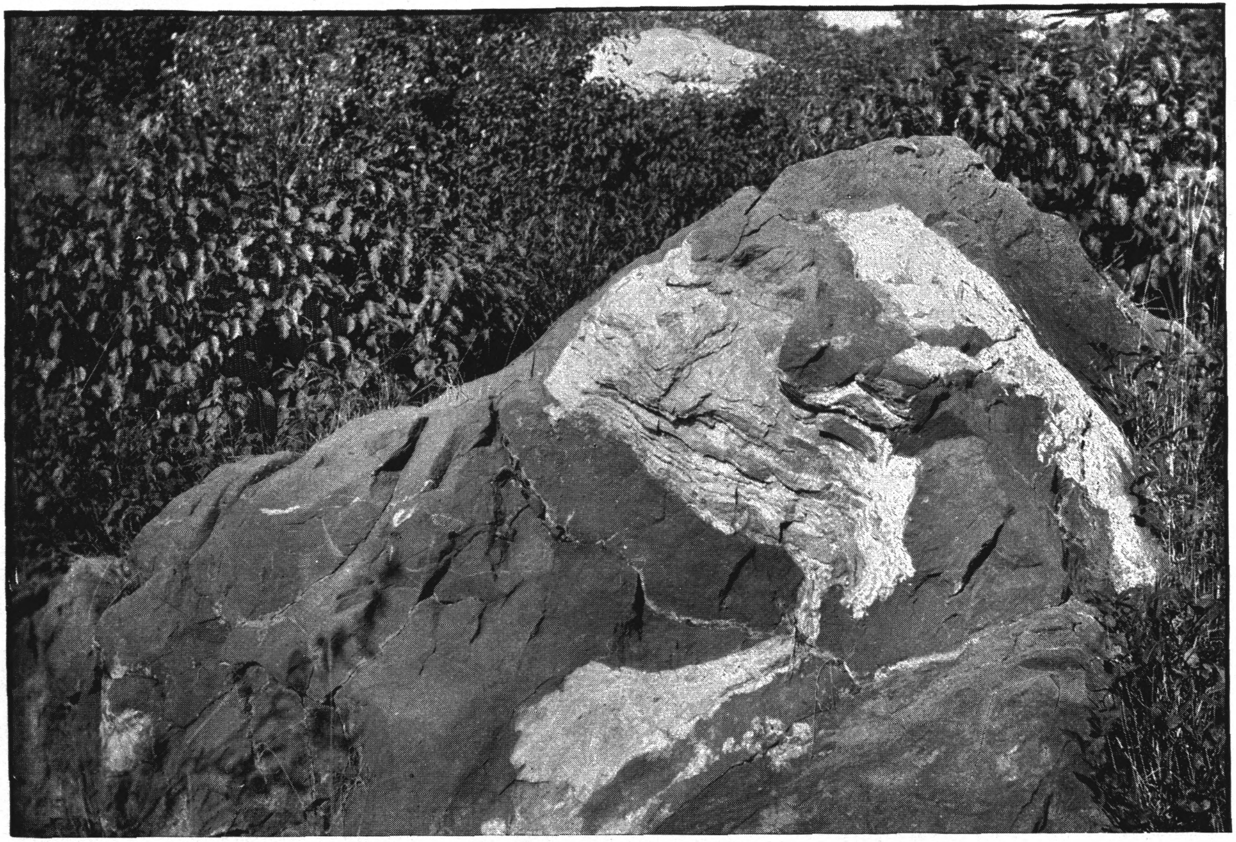
At a few places the tufaceous igneous rocks occur, showing also contemporaneous volcanic activity.

In the mapping only those areas are colored as greenstone which are shown by visible exposure or by underground working to be igneous. There can be no doubt that greenstone, in the forms of bosses and dikes, occupies a considerable area which is given the color of the Negaunee iron formation, but the positions of such greenstones are undetermined. Therefore the iron-formation color includes both the iron formation proper and unknown areas of included greenstones.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The largest area of the iron formation occupies the major part of the E. ½ of T. 47 N., R. 27 W., and the W. ¼ of T. 47 N., R. 26 W., extending from near Teal Lake on the north to the village of Palmer and Summit Mountain on the south. From the southern part of this broad central area two arms project to the northeast and east. The first arm runs in a northeast direction from Palmer, spreads out into a broad area in secs. 10 and 15, T. 47 N., R. 26 W., and terminates in sec. 3; and the second belt goes from Palmer in a zone a half to three-quarters of a mile wide to the sand plain in sec. 27, T. 47 N., R. 26 W. Its course after reaching the sand plain is undetermined. From the broad Ishpeming-Negaunee area two arms pass to the west, one near the south side of the Marquette series and the other near the north side. The southern belt has a considerable width in secs. 20 and 21, T. 47 N., R. 27 W., but farther west, as a consequence of the encroachment of the Upper Marquette series, it occupies but a narrow zone until Humboldt is reached, and it is not even certain that for a part of this distance the entire formation is not cut out. However this may be, in sec. 18, T. 47 N., R. 28 W., the formation reappears with a considerable width, and has a breadth of half a mile south of Humboldt. West of Humboldt for some distance the formation may be entirely cut off by the Upper Marquette transgression, but exposures reappear again at Champion. From Champion to the eastern side of the Republic tongue the formation is cut out. At the southeast end of the Republic tongue it swings to the south, west, and northwest, to the western side of the tongue, being again cut out at intervals. Thus the two belts are in a syncline, which is independent of the main Marquette area. West of Republic is another similar tongue.

From the main area the northern belt extends west from Ishpeming with frequent exposures, to sec. 6, T. 47 N., R. 27 W. West of this place it is known only by occasional outcrops until near Michigamme. At Michigamme and Spurr the iron formation has a considerable width, and from the latter place it extends to the west for an undetermined distance. It is wholly possible that in the area between Michigamme and sec. 4, T. 47 N, R. 28 W., the Upper Marquette transgression entirely cut out the Negaunee formation for a greater or lesser part of the distance, but in the absence of evidence of this it is mapped as continuous.



INCLUSIONS OF ACTINOLITE-MAGNETITE-SCHIST IN INTRUSIVE DIORITE, EAST OF SPURR MINE.

As has been seen, throughout much of the extent of the Negaunee formation, there are abundant masses of later intrusives, and these, rather than the iron-bearing formation itself, usually give the predominant features. In the broad Ishpeming-Negaunee area this is particulary the case, nearly all of the bluffs being composed of greenstone, the iron formation occupying the valleys between the numerous greenstone knobs and ridges. For much of this part of the area the 1,400-foot contour is approximately the boundary line between the greenstone and the iron formation. However, when the Negaunee formation becomes a jasper, or an actinolite-magnetite-schist, it is likely to become hard and resistant, and so to make important topographic features. Large outcrops of the jasper may be seen about Ishpeming and Negaunee, southeast of Palmer and at Republic. The magnetite-actinolite-schist makes prominent exposures southeast of the Goodrich mine, at Mount Humboldt, at Champion, and at Republic. In general, however, where the Ishpeming quartzite is in contact with the iron-bearing formation, the former is the more resistant rock. The same is true of the Ajibik quartzite along the Cascade Range, and where graywackes are abundant at the upper part of the Siamo slates this occupies the higher lands. Hence, upon the whole, the iron formation is not well exposed, and occupies depressions, either between intrusives within the iron formation or between the underlying and overlying formations.

FOLDING.

Beginning at the east the two arms of the iron formation constitute two synclinal troughs. As a result of the general westward pitch of the series the northern tongue is known to terminate to the east, but the termination of the southern trough is undetermined, because of its disappearance below the Pleistocene sands. As another consequence of the westward pitch these two synclinal troughs open out into the broad Ishpeming and Negaunee synclinorium. The continued westerly pitch of the series brings the quartzite of the Upper Marquette to the surface at Ishpeming, and this divides the Negaunee formation into two arms, one of which extends along the south side of the Marquette area and the other along the north side. Therefore, west of Ishpeming, the formation appears in two belts on opposite sides of the great synclinorium. At Lake Michigamme an intermediate anticline becomes prominent, and as a result of it a synclinal arm extending southeast, but terminating at Republic, is produced. West of the Republic fold is another very similar one. In the large Ishpeming-Negaunee area the secondary folding of the formation, combined with the distortions of the intrusions, produces an extremely complicated contact line, both with the underlying Siamo slate and the overlying Ishpeming quartzite. By studying these lines it is seen that the formation is rolled in a number of east-west folds, which produces several large reentrants and salients, each of which is composed of smaller reentrants and salients. The eastern swings of the contact lines mark synclines, and the western swings anticlines. Putting it in another way, the iron formation first appears above the Siamo slate in several fingers, each being a syncline. These to the west unite to form the broad area. Farther to the west the Ishpeming quartzite appears and hides the iron formation in a manner exactly similar. The secondary folds are still further modified and complicated by the intrusion of igneous masses, about which the iron formation sometimes has a quaquaversal dip. (Pl. XIX.) At other places the dip is but little modified by the intrusives. The western arms of the iron formation also have minor overfolds, which are more easily discernible when infolded with the Ishpeming quartzite, but for the most part the belts are not sufficiently well exposed to indicate the lesser folding.

A few localities in which such subordinate folds appear may, however, be mentioned. East of Palmer the general syncline of the iron formation has near its center a subordinate anticline, which causes the belt of Ishpeming quartzite at Volunteer to split just south of Palmer into

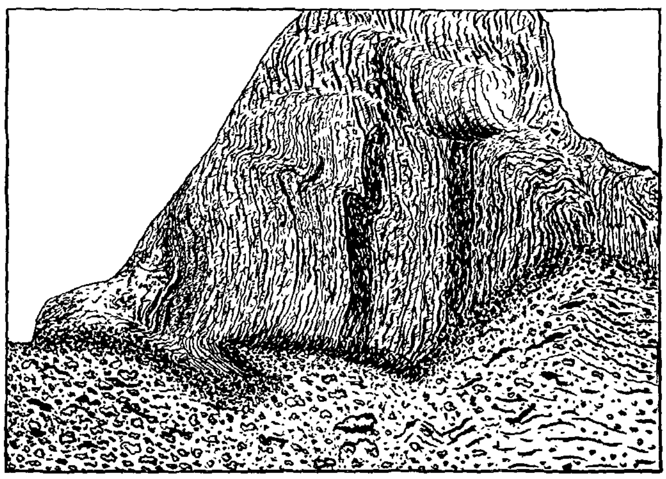
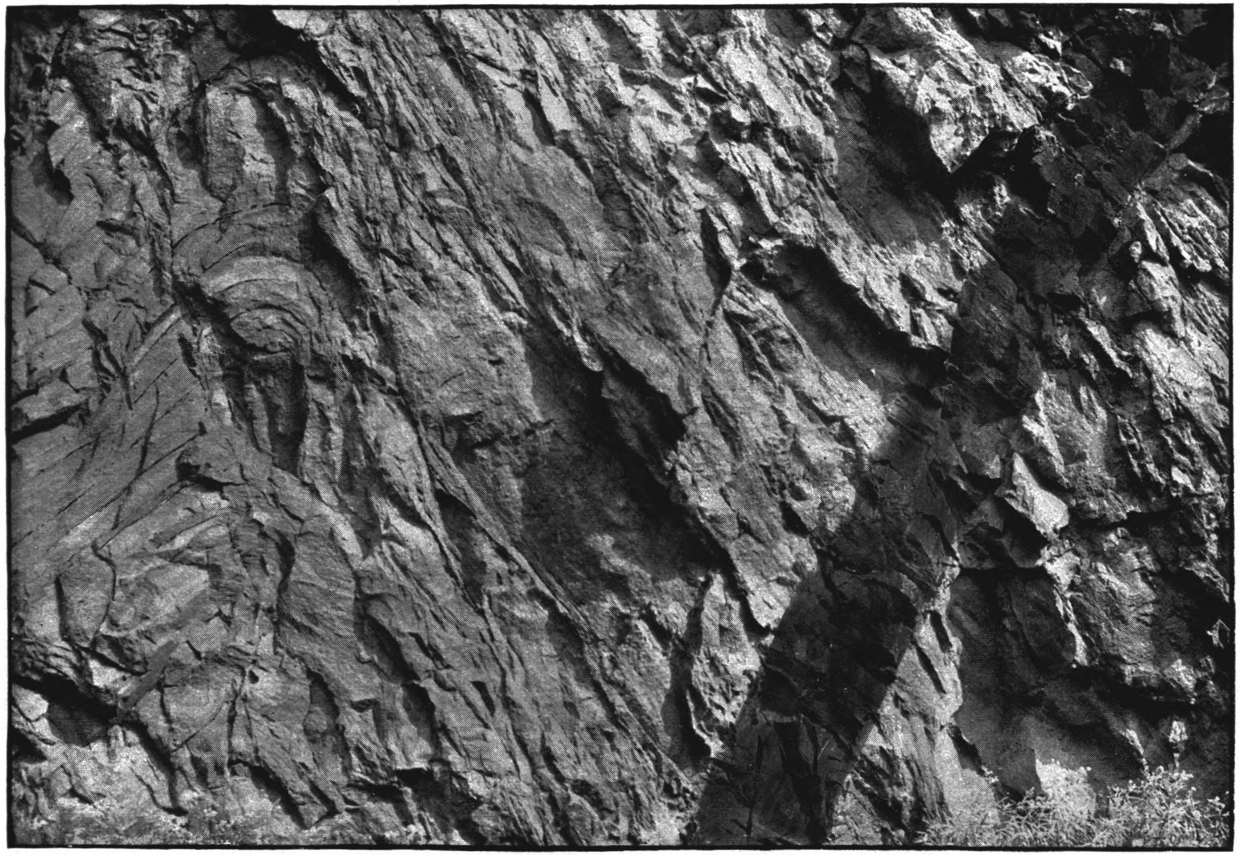


FIG. 18.—Plan of contact of Goodrich quartzite on plicated Negaunee jaspilite.

two arms. As a result of this anticline there is exposed near the railroad track east of Palmer, in the center of the iron formation, the lower members of the formation. At Humboldt the actinolite-magnetite-schist has a subordinate anticline, which causes the Ishpeming quartzite to be distributed about the great mass of actinolite-magnetite-schist in a quaquaversal fashion.

RELATIONS TO UNDERLYING AND OVERLYING FORMATIONS.

The iron-bearing formation rests conformably upon the Siamo slate or the Ajibik quartzite, and grades downward into one or the other of these formations. In passing upward within the fragmental formation nonfragmental material begins to appear and the slate or quartzite



GOODRICH QUARTZITE, WITH MINOR FOLD CUT BY DIKE, MICHIGAMME MINE.

becomes more or less ferruginous, and by an increase of the ferruginous constituent it grades up into the iron-bearing formation. This gradation may occur within a comparatively few feet, or it may require a thickness of 100 or more feet. More often than not the gradation is not a regular transition, but is accomplished by interlaminations of material which is mainly fragmental and material which is mainly nonfragmental. These interstratifications are particularly well shown at the top of the Ajibik quartzite south of Palmer and east of Negaunee, especially at a cut on the Northwestern Railway. In different places the lowest horizon of the Negaunee formation may be the sideritic slate, the actinolite-magnetite-schist, the ferruginous chert, or the jasper.

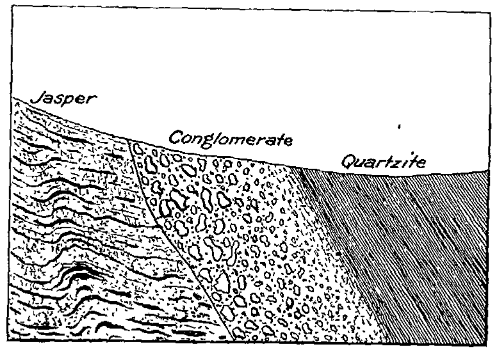


FIG. 19.—Cross-section of contact of Goodrich quartzite on plicated Negaunee jaspilite.

The overlying formation is the Ishpeming quartzite of the Upper Marquette series. The relations between the two are those of unconformity, there having been considerable orographic movement and deep erosion after the deposition of the Negaunee formation before the Ishpeming quartzite began to be deposited. The degree of folding and the amount of erosion are different in different parts of the district. Usually the discordance is not more than 5° to 15°, but locally, as at one place, the Goodrich mine, the Ishpeming quartzite cuts vertically across the plicated jasper. (Figs. 18 and 19.) In some places the erosion has cut so deep as to have entirely removed the Negaunee formation, while in other places it has a very considerable thickness. It thus follows that the contact line between the two formations is now at one horizon of the iron-bearing formation, and now at another, varying from the highest known position of the formation to its lowest horizon.

THICKNESS.

The average original thickness of the Negaunee iron formation may have been greater than its present maximum thickness, for we have no means to ascertain what part of it and of overlying formations has been removed by erosion.

If subordinate foldings are not considered, the interstratified eruptives neglected, and the maximum breadth of outcrop is multiplied by the sine of the angle of dip, this gives a thickness of about 1,500 feet, but the subordinate folding and eruptives certainly reduce this thickness somewhat—probably as much as one-third. In the broad area of the Ishpeming and Negaunee formations it is impossible to determine the thickness, for nowhere have diamond drills penetrated the underlying Teal Lake slate. The folding is here so complicated that an accurate estimate of the thickness can not be given, even of the part of the formation which is exposed and explored. It is, however, certain that the thickness is considerable, and it may be more than 1,000 feet. From what has been said in reference to erosion it is evident that the formation varies from its maximum thickness to disappearance.

PETROGRAPHICAL CHARACTER.

Macroscopical.—Petrographically the iron-bearing formation comprises sideritic slates, which may be grüneritic, magnetitic, hematitic, or limonitic; grünerite-magnetite-schists; ferruginous slates; ferruginous cherts; and jaspilite. The ferruginous cherts and jaspilite are frequently brecciated; the other kinds less frequently.

The sideritic slates are most abundantly found in the valleys between the greenstone masses in the large area south of Ishpeming and Negaunee, although they occur at other localities. These rocks are regularly laminated, fine-grained, and when unaltered are of a dull-gray color. The purest phases of them are approximately cherty iron carbonate, as shown by two analyses given below, made by George Steiger, in the laboratory of the Survey:

First analysis.

SiO_2	42.37
Fe_2O_3	1.09
FeO	31.41
CaO	.50
MgO	2.48
CO_2	21.80
Total	99.65

Second analysis.

Insoluble in HCl:	
SiO_2	26.67
Al_2O_3	.12
Fe_2O_3	.16
MgO	.10
Soluble in HCl:	
SiO_2	.30
Al_2O_3	1.18
Fe_2O_3	2.15
FeO	39.77
MnO	.29
CaO	.66
MgO	1.84
$(KNa)_2O$	.09
P_2O_5	.03
CO_2	26.20
Water below 100° C.[1]	.10
Water above 100° C.[1]	.51
Total	100.17

[1] The above determinations of water were made on the original sample.

It is unusual to find exposures of the cherty siderite-slates which have not been more or less affected by deep-seated alteration or by weathering processes. As a consequence, the iron carbonates pass by gradations, on the one hand into grünerite-magnetite-schists, and on the other into ferruginous slates, ferruginous chert, or jasper.

By oxidation of the iron carbonate the sideritic slates pass into the ferruginous slates, the iron oxide being hematite or limonite, or both. These rocks, in regularity of lamination and in structure, are similar to the sideritic slates, differing from them mainly in the fact that the iron is present in another combination.

The ferruginous cherts are rocks consisting mainly of alternating layers of chert and iron oxide, although in the iron-oxide bands chert is contained, and also in the chert bands iron-oxide is found. This iron oxide is mainly hematite, but both limonite and magnetite are sometimes present. In the field the ferruginous slates are found to grade step by step into the ferruginous cherts, and it is manifest that they have been produced from them by a rearrangement of the iron oxide and silica, with a possible introduction of extraneous silica and iron oxide. The rocks have been folded in a complicated fashion, as a result of which the layers present an extremely contorted appearance. The folded layers frequently show minor faulting. On account of the exceedingly brittle character of these rocks, they are very frequently broken through and through, and sometimes they pass into Reibung's breccias. Sometimes the shearing of the fragments over one another has been so severe as to produce a conglomeratic aspect. The ferruginous cherts are particularly abundant at the middle and lower parts of the iron-bearing formation, just above or in contact with the greenstone masses. They thus occupy an horizon within the iron-bearing formation, and in a number of cases they are between the grünerite-magnetite-schists or sideritic slates below and the jaspilite above. The rocks here named ferruginous chert are called by the miners "soft-ore jasper," to discriminate them from the hard-ore jasper, or jaspilite. This material is so called because within or associated with it are found the soft ores of the district.

The jaspilites are rocks consisting of alternate bands composed mainly of finely crystalline quartz and iron oxide. (See fig. 20.) The exposures present a brilliant appearance, due to the interlamination of the bright-red jasper and the dark-red or black iron oxides. The iron oxide is mainly hematite, and includes both red and specular varieties, but magnetite is frequently present. The jasper bands often have oval terminations, or die out in an irregular manner. The folding, faulting, and brecciation of the jaspilites are precisely like those of the ferruginous chert, except that in the jaspilite they are more severe. The interstices produced by the dynamic action are largely cemented with crystalline hematite, but magnetite is present in subordinate quantity.

In the folding of the rock the readjustment has mainly occurred in the iron oxide between the jasper bands. As a result of this, the iron oxide has been sheared, and when a specimen is cleaved along a layer, it presents a brilliant micaceous appearance, and has been called micaceous hematite. This sheared lustrous hematite, present before the dynamic movement, is discriminated with the naked eye or with the lens from the crystal outlined hematite and magnetite which have filled the cracks in the jasper bands and the spaces between the sheared laminæ of hematite. The jaspilite differs mainly from the ferruginous

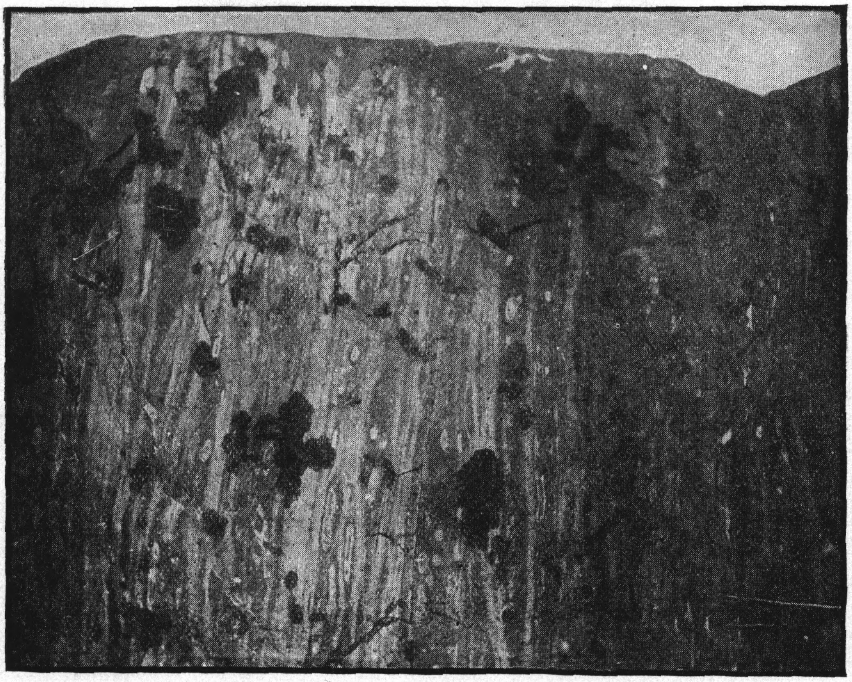


FIG. 20.—Jaspilite of Republic mine, showing white areas of chert in the red jasper.

chert, with which it is closely associated, in that the siliceous bands of the former are stained a bright red by hematite, and the bands of ore between them are mainly specular hematite, while in the cherts the iron oxide is earthy hematite. The jaspilite in its typical form, whenever present, always occupies one horizon—the present top of the iron-bearing formation, just below the Ishpeming quartzite. In different parts of the area it has a varying thickness. With this jasper, or just above it, are the hard iron ores of the district; hence it has been called by the miners, to discriminate it from the ferruginous chert, "hard-ore jasper."

An analysis of one of the typical jaspers, made by George Steiger, in the laboratory of the Survey, is as follows:

Soluble matter, chiefly iron oxide	62.36
Insoluble matter	37.64
Total	100.00

The insoluble matter contains—

SiO_2	98.91
Al_2O_3	.53
Fe_2O_3	.40
MgO	.20
Alkali oxides	.10
Total	100.14

This analysis shows that the rock is composed almost wholly of silica and iron oxides.

The grünerite-magnetite-schists consist of alternating bands, each composed of varying proportions of the minerals grünerite and magnetite and quartz. When least modified they have a structure precisely like the sideritic slates from which they grade, the grünerite-magnetite belts having taken the place of the carbonate bands. Sometimes the grünerite-magnetite-schists are minutely banded, the alternate bands consisting of dense, green grünerite and of white or gray chert, with but a small quantity of magnetite. Certain important kinds appear to be composed almost altogether of grünerite, with a little magnetite. In general, the grünerite-magnetite-schists are found at low horizons, below the ferruginous chert and jaspilite, i. e., at or near the same horizon as the sideritic slates. Frequently, also, they are below intrusive masses of diorite.

Partial analyses of two of the typical grünerite-magnetite-schists, made by Mr. George Steiger, in the laboratory of the Survey, are as follows:

	I.	II.
SiO_2	59.26	49.70
Fe_2O_3	2.42	3.10
FeO	26.49	37.19
CaO	5.03	.68
MgO	2.17	5.72
CO_2	.35	None.
Total	95.72	96.39

These analyses show that the rock is composed essentially of quartz and impure grünerite. Both analyses indicate that the amphibole is intermediate between grünerite and actinolite, but upon the whole is much nearer the former than the latter.

It appears that the ferruginous slates, ferruginous cherts, and jasper form in the zone of weathering, and that the grünerite-magnetite-schists develop in the zone of deep-seated alteration. The different characters are then due to original position within the formation and to subsequent environment rather than to difference in the original rock.

In fullest section the Negaunee formation exhibits, therefore, the following stratigraphy: At the bottom are the sideritic slate and grünerite-magnetite-slate; above these, ferruginous slate; above this, ferruginous chert, and at the top of the formation, jaspilite. While this is the common order, in a given locality one or more of these members may be absent. For instance, at Republic only the grünerite-magnetite-schists, the ferruginous chert, and the jaspilite are found. South of the Saginaw mine, at the base, is the grünerite-magnetite-schist; at the intermediate horizons, the ferruginous chert, and at the top, the jaspilite. South of Palmer the jaspilite occupies the whole breadth of the formation between the Ishpeming quartzite and the Ajibik quartzite. Farther to the east, however, where the formation has a greater thickness, the ferruginous chert occurs below the jaspilite. At and south of Negaunee the full succession is found. Beginning at the Jackson mine and passing southward we find at the top of the formation magnificent exposures of jaspilite; below this are numerous open pits, which give typical exposures of the ferruginous chert. This grades down into the ferruginous slate of the Davis mine, and continuing southward we find within the valleys between the greenstones the grünerite-magnetite-schists and the very little altered sideritic slate.

Microscopical.—The kinds of rocks found in the iron-bearing member of the Lower Marquette series and their relations to one another are very similar to those of the iron-bearing member of the Penokee and Animikie series, which have been described in great detail. Also, the microscopical characters of the different phases of rocks are similar to those of the Penokee series. In fact, so remarkable is the likeness that, with a restatement of localities, what has been written in reference to the Penokee and Animikie iron formations might be applied almost verbatim to the Marquette iron-bearing formation. Therefore, for a detailed description of the different phases of the iron-bearing formation and the manner in which the original rock grades into the other phases, reference is made to Monograph XIX, chapter 5, pages 182–268.

A very brief description will, however, be given of the general character of the different phases of the iron-bearing formation, and a more detailed statement will be made in reference to those points in which there are differences between the Lower Marquette and the Penokee iron-bearing formations.

In the purest phases of cherty siderite-slate there is a continuous mass of siderite, which contains separate granules or irregular complex areas of cherty silica, small crystals of magnetite, and needles of actinolite or grünerite. The silica is rarely partly amorphous, being in minute opaline droplets, but is more commonly completely individualized quartz, the grains varying in the different slides from 0.01 to 0.03 mm. in diameter. The siderite is in closely packed, small rhombohedra. Upon the weathered surfaces the siderite is entirely oxidized, being changed into hematite or limonite, with pseudomorphous forms. In this iron oxide is contained cherty silica, identical with that in the unaltered part of the slides. Between the two there is a transition zone, in which the various stages of alteration are seen, from the unchanged siderite to the secondary hematite. In one of the finest instances the transition band is broad, and there are seen many rhombohedra of siderite surrounded by bands of beautiful, blood-red, translucent hematite. These borders vary from mere films to those so broad that but a minute speck of the siderite remains. If the oxidized portion of the slide were seen by itself it would be regarded as a ferruginous slate, with which it is in every respect identical, but in this case it can not be doubted that the siderite is the original source of the hematite. When the siderite is less abundant and the chert more plentiful, the rhombohedra of siderite are set in a matrix of chert, which may consist wholly of individualized quartz, but which sometimes apparently contains some opaline silica. Oftentimes bands consisting largely of silica alternate with bands consisting largely of siderite. In the less pure phases, near the base of the Negaunee formation, the cherty siderite in some cases alternates with strata of an impure clayey rock, approaching the ferruginous Siamo clay-slates. In other cases, mingled with the siderite itself, is fragmental material, including both quartz and feldspar, and other alteration products. Not infrequently within these semifragmental rocks are rhombohedra of siderite, and along cracks and joints all transitions between the impure siderite and a ferriferous or cherty slate, partly fragmental and partly nonfragmental, may be seen.

When the sideritic slates are altered, not by weathering, but by deep-seated metasomatic action, there develops abundant magnetite, and a white amphibole, nonpleochroic in thin section, which will be called grünerite. There is thus produced a magnetite-grünerite-siderite-slate, intermediate between the sideritic slates and the typical magnetite-grünerite-schists. It appears, as in the cases of the Penokee and Animikie series, that as the siderite has decomposed there has been an abundance of silica present, and conditions not favorable to oxidation, so that the silica has united with the iron alone, producing grünerite, or with the iron, calcium, and magnesium, producing a mineral intermediate between grünerite and actinolite. The iron which does combine with the silica, not being completely oxidized, is in the form of magnetite, and hence we have the first stage of the development of the magnetite-grünerite-schists from the sideritic slates.

The grüneritic and magnetitic schists may vary from nearly pure grünerite-schists to nearly pure magnetite-schists. However, the more common phase is the grünerite-magnetite-schist. Grünerite, magnetite, and quartz are the three important constituents, but in some areas quartz is in subordinate quantity. The minerals are usually concentrated to some extent into bands, although a layer composed chiefly of any one of the three always includes a greater or lesser quantity of the other two. In many cases within the felted mass of grünerite or magnetite are found many rhombohedra of siderite, and this siderite has such relations to the grünerite and magnetite as to suggest that from it have developed these minerals. We thus have evidence of the transition of the sideritic slates into a grünerite-actinolite-schist. When the transformation is complete, there remains no evidence of the change, as the rock then consists of a completely interlocking crystalline mass of the three minerals, grünerite, magnetite, and quartz.

Not infrequently with the magnetite is a greater or lesser quantity of hematite. In some cases this appears to have been an early development, simultaneous with the magnetite, and in other cases has resulted from the weathering of the rock, developing either from the magnetite or from the grünerite. Less frequently limonite is found in similar relations. A common hornblende appears in some cases to be separable from the grünerite by a decided pleochroism, and the two often occur in the same section or interground in the same individual. Not infrequently the quartz has a peculiar parallel arrangement, with its longer axes in a common direction, and has with this an undulatory extinction. This is taken as indicating that these rocks have been subjected to stress during or subsequent to the time the quartz developed. The grünerite and magnetite are closely associated, often penetrating each other, and are also found within and penetrating the quartz, showing that the minerals have developed to some extent simultaneously, although the quartz appears on the whole to be rather later than the grünerite and magnetite. In the finer-grained phases opaline silica is also present. As in the case of the sideritic slates, some of the grüneritic schists contain interstratified or intermingled fragmental material, and the rock by transition passes downward into the fragmental Siamo slate. In these kinds ordinary hornblende has abundantly developed, and chlorite and biotite are important secondary products. Sometimes associated or included in the magnetite-grünerite-schists is a good deal of secondary garnet, and this is particularly abundant adjacent to diorites, showing that its development is due to the contact action of the intrusives.

The development of the grünerite-magnetite-schists, in opposition to the ferruginous slates, cherts, and jaspers, seems to have been favored by deep-seated metasomatic changes, rather than by weathering processes. This is indicated by the following facts: Where the weathering has been active, the ferruginous slates and cherts are found rather than the grünerite-magnetite-schists; the grünerite-magnetite-schists where weathered have been partly transformed into the ferruginous slates or cherts; the grünerite-magnetite-schists are usually closely associated with the diorites, and this suggests that the heat of these intrusives increased the activity of percolating waters; possibly also the heat helped to decompose the iron carbonate; the diorites may also have furnished alkalies to assist in the solution of silica. The silica in solution united with the protoxides present to produce the grünerite, the excess of iron oxide, not completely oxidized, remaining as magnetite.

The ferruginous slates consist of a background of cherty silica, like that of the sideritic slates, closely intermingled and associated with hematite and limonite, the latter minerals occupying the place of the siderite in the sideritic slates. If the iron oxides are abundant, the slides consist of a continuous ramifying mass of hematite and limonite, within which the numerous patches or particles of cherty silica are set. The manner in which this phase of rock developed from the sideritic slate has already been indicated.

The ferruginous cherts differ from the ferruginous slates chiefly in that the silica has been more extensively rearranged. As a consequence of this the chert and iron oxides are more or less concentrated in alternating bands, rather than as a mingled, homogeneous mass, as in the ferruginous slates. However, the chert bands are never free from the iron oxide, nor are the iron oxide bands ever free from the chert. Between almost pure iron oxide and almost pure chert bands there are all gradations. The silica of the chert is usually completely individualized, but in different sections varies from partly amorphous through finely crystalline to rather coarsely crystalline quartz. The quartz which does not show evidence of much rearrangement is very like in size of granules and in appearance to the quartz of the sideritic slates, but that in viens and filled areas is much more coarsely crystalline. In arrangement the particles of iron oxide appear to be wholly independent of the quartz. There is no apparent concentration of the iron oxides between the quartz grains, but they occur concentrated in laminæ or as separate flecks included in the grains of quartz, just as though they were all in their present positions before the quartz began to crystallize. In the ferruginous cherts which are near the ore bodies cavities are very common, due to the solution of the quartz. These cavities have often been subsequently partly or wholly filled by hematite. In all these particulars these ferruginous cherts are similar to those from the Penokee and Animikie districts, but they differ from them in not showing extensively the somewhat remarkable concretionary structure characteristic of these formations, although in a few places this is well developed.

The Marquette ferruginous cherts have been subjected to profound dynamic action, and the brittle rock has become shattered through and through, producing innumerable cracks and fissures, and not infrequently Reibung's breccias. Within the spaces thus formed secondary hematite and magnetite in well-defined crystals have infiltrated. By the crystal outlines the secondary iron oxide can frequently be discriminated from that present before the shearing occurred. The secondary action has been so long continued within the ferruginous cherts that it could not be expected that residual siderite should be found, yet in one or two cases a small quantity occurs. However, in the field the gradations are so complete that one can not doubt that these rocks were produced by the alteration of the original sideritic chert, combined with secondary infiltration. It is highly probable that much of the iron oxide and much of the silica now present were derived from an iron carbonate once above the ferruginous cherts, but now removed by solution and erosion. The ferruginous slates represent the kinds of rocks produced by the simple oxidation in place of the original sideritic slates, and from them by the secondary actions described are produced the ferruginous cherts. As in the case of the sideritic slates and the grünerite-magnetite-schists, fragmental material is occasionally recognized.

In thin section the jaspilites have a minutely laminated character, each of the coarser bands, as seen in hand specimen, being composed of many laminæ, due to the irregular concentration of the iron oxide. These laminæ are of greatly varying width. They unite and part in a most irregular fashion, producing a mesh-like appearance, and frequently laminæ disappear, as do the coarser bands. The complex bright-red jasper bands are mainly composed of finely crystalline cherty quartz, but they are everywhere stained with minute particles of blood-red hematite. The particles of quartz average less rather than more than 0.01 mm. in diameter, and each of these minute grains contains one or more particles of hematite. These are concentrated in laminæ or are separate flecks included in the quartz grains. In some cases the hematite appears to be somewhat concentrated between the grains, but in general it is arranged in entire independence of them, as though it were present before the quartz had crystallized. The ferruginous bands contain a predominating amount of iron oxide, but in them is included much quartz, exactly similar to that of the jasper bands. The original, translucent, red, sheared hematite is easily discriminated from the crystalline hematite and magnetite.

The folding, faulting, fracturing, and brecciation, spoken of in hand specimen, are beautifully shown under the microscope. The resultant cracks and crevices are filled with secondary quartz and crystalline hematite and magnetite. This quartz is much more coarsely crystalline than the older quartz, the grains oftentimes averaging from 0.05 to 0.1 mm. in diameter. While much of this secondary quartz occurs in grains which cut across the original lamination of the rock, a good deal of it has entered parallel to the lamination. Its likeness to the vein quartz and its coarseness readily discriminate it from the earlier quartz. The crystalline hematite and magnetite also help to fill the veins and the spaces between the micaceous hematite laminæ where accommodation has taken place. The secondary materials usually have entirely filled the spaces, thus completely healing the rock, and because so much of them has entered parallel to the original lamination this structure is emphasized by the secondary impregnations.

It has been noted that the jaspilite is characteristic of the uppermost horizon of the iron-bearing formation, that is, it is immediately below the next overlying series. This contact zone has been one of the great planes of accommodation, and thus the dynamic effects upon the jasper are explained. Between the jasper horizon and that at which the ferruginous cherts occur is a transition zone. In this the layers of siliceous material sometimes have borders of red, iron-stained quartz. It has been explained that the chief differences between the jaspilites and ferruginous cherts are the blood-red character of the minute hematite particles and the micaceous character of the ferruginous layers of the former. It appears highly probable, therefore, that the dynamic movements have transformed the ferruginous chert into the jasper, the layers of brown hematite being sheared into micaceous hematite, and the inclusions of brown hematite being changed into the blood-red variety.

The foregoing general description is of the rocks as they occur in the eastern part of the district. At the west end of the district the predominant varieties of the Negaunee formation are the grünerite-magnetite-schists and the jasper. There are also subordinate amounts of ferruginous chert. In this part of the area the rocks are much more coarsely crystalline than in the eastern part of the district. The quartz grains in the extreme western end of the area have diameters averaging from 0.10 to 0.15 mm., and in the southwest arm they average about 0.20 to 0.40 mm. and run as high as 1 mm. It will be seen that the size of the grains is many times greater than in the Ishpeming-Negaunee area, where the average diameters vary from less than 0.01 mm. to 0.03 mm. The quartz grains are of sufficient size to show distinctly undulatory extinction and fracturing, the latter rarely in a rectangular manner. In the more sheared varieties they are arranged to some extent with their axes in a common direction. The grünerite also is much more coarsely crystallized. Exact comparisons of these with the grünerite needles of the Ishpeming area are, however, difficult. The jaspers of the western end of the district afford a good opportunity to observe the relations of the included particles of hematite and the grains of quartz. The former appear just as if they were in their present positions before the quartz crystallized and the latter mineral had taken the remaining space. There is no tendency to concentration of this hematite at the borders of the quartz grains or in the cracks formed by their fracturing. In the jaspers and in some of the more quartzose grünerite-magnetite schists is also a beautiful concretionary structure, exactly similar to that of the ferruginous cherts of the Penokee district. The concentric zones of red hematite, separated by a greater or lesser distance, appear as if painted upon the quartzose background, the grains of which seem in no way to be affected by the hematite. The crystals of hematite and magnetite were still earlier, or else have developed where the red hematite and the quartz have been dissolved, for they are scattered at random through the section, interrupting the concentric zones of hematite at many places. In some slides the concretions are decidedly flattened by pressure.

The foregoing facts show that in these jaspers the minerals, with the possible exception of the crystals of hematite and magnetite, had assumed their present relations before the last dynamic movement. The concretions, the coarsely crystalline character of the rocks, and the absence of the sideritic and ferruginous slates imply a much more extensive recrystallization of the entire formation than has taken place in the eastern part of the district. If the original rocks in this part of the area were of the same character as about Ishpeming and Negaunee the silica must have entirely recrystallized. It is to be noted that in this part of the area the other formations of the Marquette series are also much more profoundly metamorphosed than they are farther east. Therefore the unusually modified character of the rocks of the Negaunee formation accords with what would be expected from a study of the other formations.

THE IRON-ORE DEPOSITS

The ore horizons.—The ore deposits, according to position, may be divided into three classes, (1) those at the bottom of the iron-bearing formation, (2) those within the iron-bearing formation, and (3) those at the top of the iron-bearing formation. (Pl. XXII, fig. 1.) By the last is meant the horizon immediately below the next overlying formation, the Goodrich quartzite. The ore deposits of the second class are frequently at the top of the ore formation as now exposed, but not at the uppermost horizon of the formation. The first two classes of ores are generally soft, and the adjacent rock is ferruginous chert or "soft-ore jasper," while those at the top of the iron-bearing formations are hard specular ores, or magnetite, and the adjacent rock is jaspilite, also called "specular jasper" and "hard-ore jasper." This last class of deposit frequently runs up, past the unconformity, into the Upper Marquette-Goodrich quartzite, and sometimes some of these ore bodies are almost wholly in this position. Logically the consideration of these deposits ought to be deferred until the Goodrich quartzite is treated, but they are so closely connected genetically and in position with the Lower Marquette ore deposits that they are here considered.

While the larger number of ore bodies can be referred to one or another of these three classes, it not infrequently happens that the same ore deposit belongs in two of the classes, or partly in one and partly in the other. To illustrate: The Upper Marquette transgression may so nearly cut through the iron formation that an ore deposit may extend from the bottom of the formation to the top. However, in these cases the ore bodies are usually hard, and upon the whole are more closely allied to the third class than to the first. Very frequently, also, a single ore deposit may have its upper part at the topmost horizon of the iron-bearing formation, and this part be a specular ore, while the

PLATE XXII.

PLATE XXII. THE ORE DEPOSITS OF THE MARQUETTE DISTRICT.

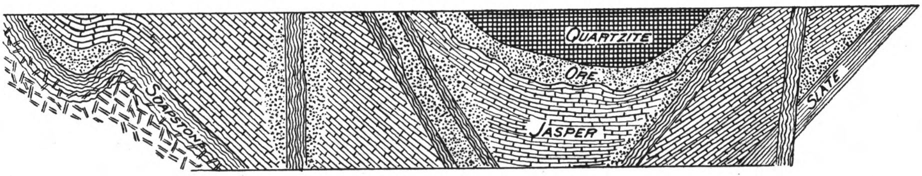
Fig. 1. Generalized section showing relations of all classes of ore deposits to associated formations. On the right is soft ore resting in a V-shaped trough between the Siamo slate and an eruptive dike of soapstone. In the lower central part of the figure the more common relations of soft ore to vertical and inclined dikes cutting the jasper are shown. The ore may rest upon an inclined dike, between two inclined dikes and upon the upper of the two, or be on both sides of a nearly vertical dike. In the upper central part of the figure are seen the relations of the hard ore to the Negaunee formation and the Ishpeming quartzite. At the left is soft ore resting in a trough of soapstone which grades downward into diorite.

Fig. 2. Sharply plicated jasper (black belts) and ore (white areas) showing shattering of the jasper and concentration of the ore. The ore is proportionally greater where the folding has been sharpest. Drawn from photograph from southeast corner of Republic horseshoe.

Fig. 3. Horizontal section of chimney of ore on east side of Republic horseshoe. The left side of the ore is bounded by cross-joints. The right side is bounded in part by a sharp flexure passing into a joint, and in part grades into the lean banded jasper and ore. Scale: 20′=1″.

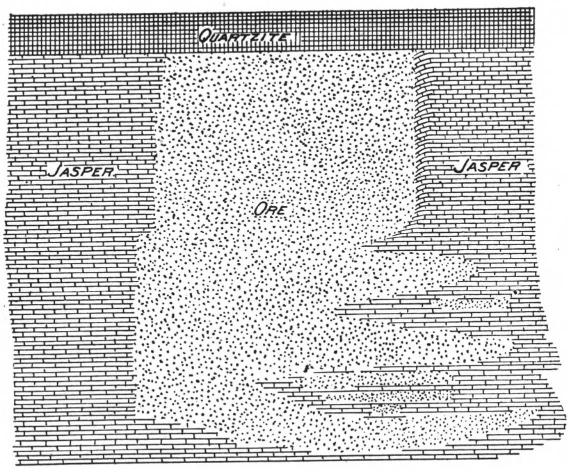
Figs. 4, 5, and 6. Three cross-sections of ore in trough of soapstone grading downward into diorite. In fig. 4 the ore deposit is solid. In fig. 5 a dike offshoots and nearly separates this ore body into two parts. In fig. 6 the two dikes divide the same ore body into three parts. Scale: 200′=1″.

Fig. 7. Cross-section of National mine. On the left is soapstone grading into diorite. Above this is hard ore, and overlying the hard ore are interstratified conglomerate, quartzite, and schist. The ore is here plainly due to a replacement of the silica of the different sedimentary bands by ore, although the orginal conglomerate was heavily ferruginous. Scale: 200′=1″.

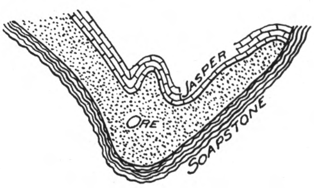


1

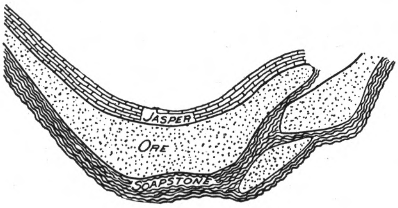
2



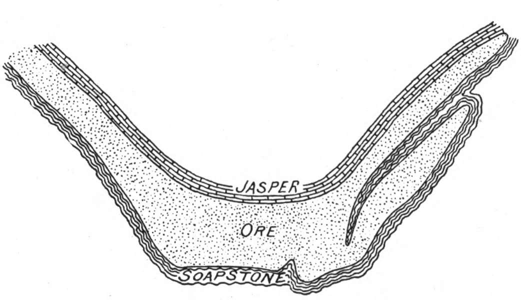
3



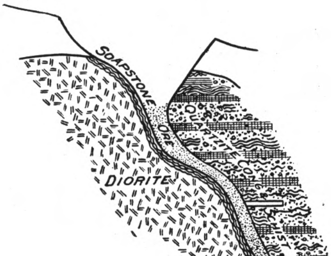
4



6



5



7

THE ORE DEPOSITS OF THE MARQUETTE DISTRICT.

PLATE XXIII.

579

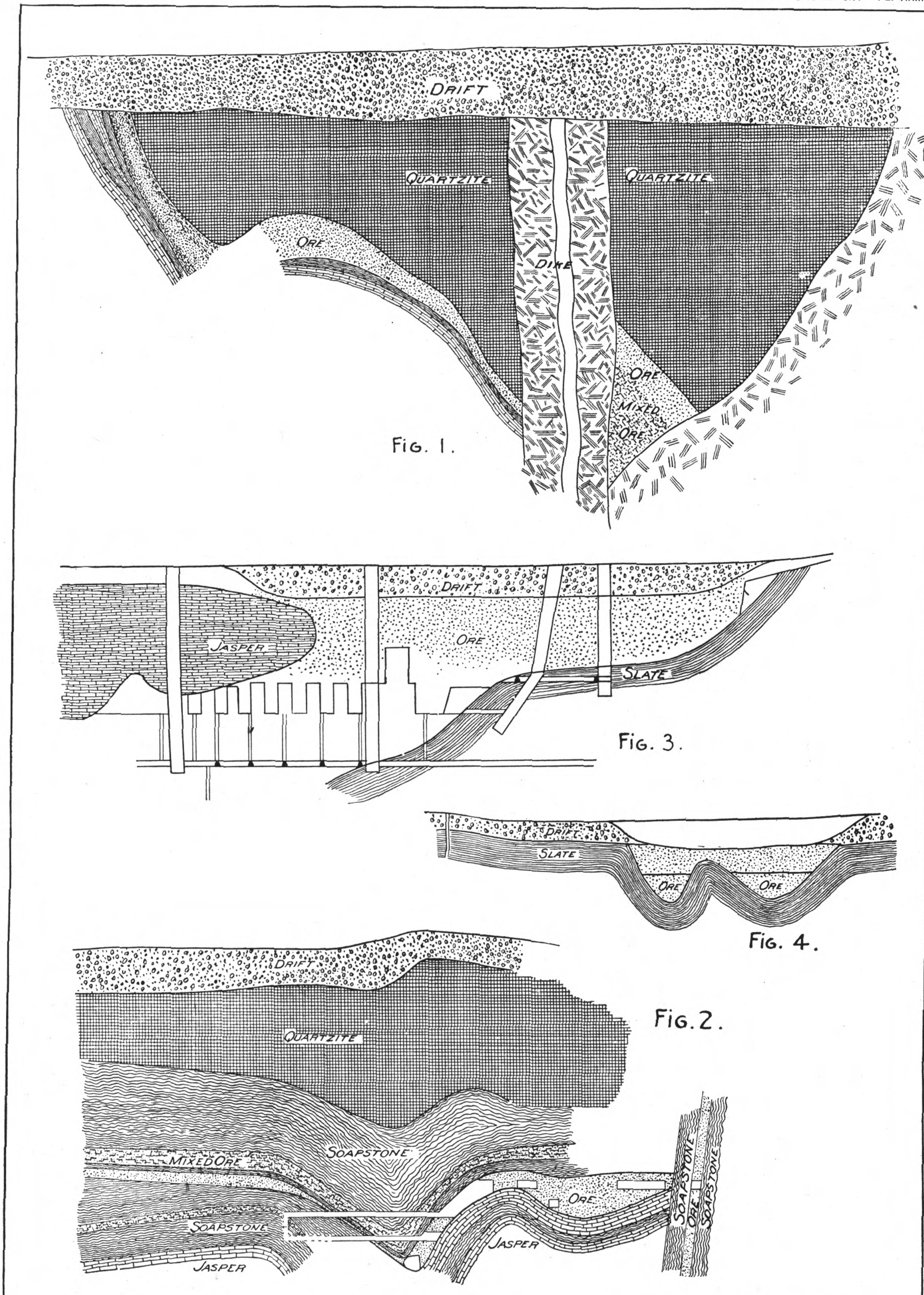
PLATE XXIII. THE ORE DEPOSITS OF THE MARQUETTE DISTRICT.

Fig. 1. Cross-section of Section 16 mine, Lake Superior Iron Company. On the right is a V-shape trough made by the junction of a diorite mass and a dike. The hard ore is between these and below the Ishpeming quartzite. On the left the hard ore again rests on soapstone, which is upon and interstratified with jasper, and is overlain by the Ishpeming quartzite. Scale: 200′ = 1″.

Fig. 2. Cross-section of the Barnum mine showing hard ore resting either upon folded soapstone or upon jasper, and overlain by soapstone. At the right of the figure is seen a layer of ore between two soapstone dikes. Scale: 200′ = 1″.

Fig. 3. Longitudinal section of the Queen, Prince of Wales, and South Buffalo mines, showing the soft ore resting upon an impervious foot-wall of Siamo slate, and grading upward into jasper. Scale: 200′ = 1″.

Fig. 4. Cross-section of same showing how the slate is folded into two troughs, which is shown by the longitudinal section (fig. 3) to have a western pitch. Scale: 200′ = 1″.



THE ORE DEPOSITS OF THE MARQUETTE DISTRICT.

lower part is wholly within the iron-bearing formation and is soft ore. Sometimes there is a gradation between the two phases of the deposit, but more frequently the two bodies are separated by a dike, now changed to soapstone or paint rock.

(1) The ore deposits at the bottom horizon (Pl. XXIII, figs. 3 and 4) can occur only where the lowest horizon of the formation is present; that is, they are confined to that part of the formation in contact with the Siamo slate or the Ajibik quartzite. Hence they are found only along the outer borders of the formation, and do not occur in the broad Ishpeming-Negaunee area. The best examples of these deposits are those occurring at the Teal Lake Range, which includes the Cleveland Hematite mine, and the mines east of Negaunee, including the Buffalo, Queen, Blue, and other mines. These ore deposits have as their foot-wall the Siamo slate. A striking fact about these deposits is that all of those mentioned, and all of those known, occur at places where the Siamo slate is folded so as to form a trough. By reference to the map (Pl. XIII) it is seen that all the Teal Lake mines occupy a place where the iron formation curves to the north and then swings back to its original course, the ore deposits thus resting upon a southward-pitching trough of the slate. Still more striking is the occurrence east of Negaunee. Here the ore bodies occur at places where the slate is folded so as to furnish sharply pitching synclinal troughs, which plunge to the west. (Pl. XXIII, figs. 3 and 4.) It is further found, by an examination of the workings, that the iron-bearing formation is cut by a series of vertical dikes, and that the conjunction of these dikes with the foot-wall slate often forms sharp V-shaped troughs. This is particularly clear in the case of the Cleveland Hematite mine, where, between a series of vertical dikes and the Siamo slate, the ore bodies are found. By comparing this occurrence with the ore deposits of the Penokee Range,[1] it will be seen that they are almost identical, in each case there being on one side of the formation an impervious slate and quartzite, and upon the other an impervious dike, the two uniting to form pitching troughs.

(2) The typical area for the soft-ore bodies within the iron formation is that of Ishpeming and Negaunee. Here belonging are such deposits as the Cleveland Lake, Lake Angeline, the Lake Superior Hematite, the Salisbury, and many others. When these deposits are examined in detail, it is found that the large deposits always rest upon a pitching trough, composed wholly of a single mass of diorite (Pl. XXII figs. 4–6), or on a pitching trough, one side of which is a mass of diorite and the other side of which is a dike joining the diorite. The underlying rock is called diorite, although immediately in contact with the ore it is known as paint rock or soapstone by the miners.

[1]The Penokee Iron-bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise. Mon. XIX, U. S. Geol. Surv., pp. 268-294.

However, a close examination of numerous localities shows that the diorite changes by minute gradations into the schistose soapstone, and this into the paint rock, and that therefore these phases are merely parts of the diorite which have been profoundly altered by shearing and leaching processes, and which have been strongly impregnated by iron oxide. Frequently the thinner dikes are wholly changed to paint rock or soapstone, or to the two combined. The larger number of these troughs are found along the western third of the Ishpeming-Negaunee area. By examining the map (Pl. XIII) the masses of diorite may be seen inclosing several westward opening bays which are occupied by the iron formation. Conspicuous among these are the Ishpeming basin, the northern Lake Angeline basin, the southern Lake Angeline basin, and the Salisbury basin. In each of these cases the diorite forms an amphitheater about the rocks of the iron-bearing formation. Areas of iron formation open out to the west into the main area, and thus the troughs have a westward pitch. In the case of Lake Angeline, an east-and-west dike cuts across the basin south of the center, and this, combined with the diorite bluff to the north and to the south, here forms two westward-pitching troughs. The northernmost of these has the greatest ore deposits of the Marquette district, containing many millions of tons of ore.

(3) The hard-ore bodies, mainly specular hematite, but often including a good deal of magnetite, occur, as has been said, at the top of the iron-bearing formation, immediately below the Goodrich quartzite and within the lower horizons of the Goodrich quartzite. (Pl. XXII, figs. 1, 3 and 7, and Pl. XXIII, fig. 2.) As typical examples of mines of this class may be mentioned the Jackson mine, the Lake Superior Specular, the Volunteer, the Michigamme, Riverside, Champion, Republic, and the Barnum. Also, as interesting deposits, giving the history of the ore, may be mentioned the Kloman and the Goodrich. In all of these deposits the associated rock of the iron formation is jaspilite or grünerite-magnetite-schist, usually the former. The only important mine in which the grünerite-magnetite-schist occurs is the Champion. These ore deposits, bridging two different geological series, can not be separated in description, for frequently they weld together the Upper Marquette-Goodrich quartzite formation and the Lower Marquette-Negaunee formation. As in the cases of 1 and 2, all of the large ore deposits belonging to this third class have at their bases soapstone or paint rock. (Pl. XXIII, fig. 2, and Pl. XXVI, fig. 1.) In those cases in which the soapstone is within the Negaunee formation it is a modified diorite, or a diorite in conjunction with a dike or dikes. When the ore deposits are largely or mainly in the Goodrich quartzite the basement rock may again be a greenstone, but also it may be a layer of sedimentary slate belonging to the Goodrich quartzite. These different classes of rocks are, however, not discriminated by the miners,

and are lumped together as soapstone or paint rock. Also, as in the cases of 1 and 2, whenever the deposits are of any considerable size the basement rock is folded in the form of a pitching trough, or else by a union of the mass of diorite with a dike or by a union of either one of these with a sedimentary slate an impervious pitching trough is formed. Perhaps the most conspicuous example of this is the Republic mine (Pl. XXVI), but it is scarcely less evident in the other large deposits. However, a few small deposits—chimneys and shoots—of ore occur at the contact of the Negaunee and Ishpeming formations, where no soapstone has been found. As examples of ore deposits which are largely or wholly within the Upper Marquette may be mentioned the Volunteer, Michigamme, Champion, and Riverside. These partly recomposed ores differ in appearance from the specular hematite or magnetite of the Lower Marquette in having a peculiar gray color and in containing small fragmental particles of quartz and complex fragmental pieces of jasper, and frequently also sericite and chlorite are discovered with the microscope.

In any of these classes the deposits may be cut into a number of bodies by a combination of dikes or diorite masses. A deposit which in one part of the mine is continuous, in another part of the mine, by a gradually projecting mass of diorite which passes into a dike, may be cut into two deposits, and each of these may be again dissevered, so that the deposit may be cut up into a number of deposits separated by soapstone or paint rock. (Pl. XXII, figs. 4–6.) In some cases the ore deposits have a somewhat regular form from level to level, but the shape of the deposit at the next lower level can never be certainly predicted from that of the level above. Horses of jasper may appear along the dikes or within the ore body at almost any place. The ore bodies grade above and at the sides into the jasper in a variable manner. As a result of the combination of these uncertain factors, most of the ore bodies have most extraordinarily irregular and curious forms when examined in detail, although in general shape they conform to the above conditions of occurrence.

While these different classes of ore bodies have the different features indicated above, they have great common features. They are confined to the iron-bearing formation. They occur upon impervious basements in pitching troughs. The impervious basement may be a sedimentary or igneous rock, or a combination of the two. When the ore deposits are of considerable size the plication and brecciation of the jasper are usual phenomena. (Pl. XXII, fig. 2.) Frequently this shattering is concomitant with the folding into troughs or with the intrusion of the igneous rocks. When the passage of the ore bodies into the jasper is examined in detail, it is found that a jasper band, if followed toward the ore, instead of remaining solid, becomes porous and frequently contains considerable cavities. These places in the transition zone are lined with ore. In passing toward the ore deposit more and more of the silica is found to have been removed, and the ore has replaced it to a corresponding degree. An examination at many localities shows this transition from the banded ore and jasper to take place as a consequence of the removal of the silica and the substitution of iron oxide. In such instances the fine-grained part of the ore is often that of the original rock, while the coarser crystalline material is a secondary infiltration. It is not infrequently the case, however, that the ore deposits abruptly terminate along a joint crack or fracture. (Pl. XXII, fig. 3.)

Origin of the ores.—The facts given in the foregoing pages in reference to the iron-bearing formation and its origin, combined with the peculiar occurrence of the ores, indicate with certainty the main features of the origin of the ore deposits.

While the ore deposits of the Lower Marquette series have a greater variety of form and relations than those of the Penokee district, it is evident that the conditions governing their formation are much the same. In both districts the material immediately underlying the ore is relatively impervious to water. In the cases of the deposits resting upon soaprock this lack of porosity is nearly complete. Most of the ore bodies are in troughs in both districts; the ore bodies in both in longitudinal section have a pitch; in both the many phases of material found in the iron-bearing formation are nearly the same, and in both is found plentiful residual iron carbonate. It is therefore thought that the explanation of the origin of the ores in the Penokee district is applicable, with few modifications, to those of the Marquette district, although the larger number of the deposits of the latter belong to an older series.

The forms, attitudes, and relations of the ore deposits render it evident that they are not eruptives. (Pls. XXII, XXIII.) No eruptive would be found in such strange shapes and relations. It is equally certain that these irregular masses of ore are not altogether formed by direct sedimentation, although a considerable part of the iron oxide in an ore body may be an oxidation in place of a sedimentary iron carbonate.

All these facts bear toward the conclusion that the ore has been secondarily enriched by the action of downward percolating water, since the ore deposits occur at places where percolating waters are sure to be concentrated. The soaprock accommodates itself to folding without fracture, and, while probably allowing more or less water to pass through, acts as a practically impervious stratum along which water is deflected when it comes in contact with it. It is a common opinion among miners that a few inches of soaprock is more effective in keeping out water than many feet of the iron-bearing formation. On the other hand, the brittle, siliceous ore-bearing formation has been fractured by the folding to which it has been subjected, so that where these processes have been extreme water passes through it like a sieve. That the tilted bodies of diorite or soaprock, especially when in pitching synclines or forming pitching troughs by the union of dikes and masses of diorite, must have converged downward-flowing waters is self-evident. It is also clear that the contact and shear plane between the Ishpeming quartzite and the Negaunee formation, that is, the plane of unconformity between the Upper Marquette and Lower Marquette series, must have been a great horizon for downward-flowing waters.

If it is true that the whole of the iron-bearing formation was originally a lean, cherty carbonate of iron, with perhaps some calcium and magnesium, or if we go further back than the ferruginous cherts and jaspers, in order to produce the ore two things must have occurred: First, the further concentration of iron oxide in the places where the ore bodies are found; and second, the removal of silica from these places.

The final concentration of the ores occurring at the contact of the Upper Marquette and Lower Marquette series must have taken place later than Upper Marquette time. This is indicated by the fact that the unconformable formations are often welded together by the iron ore. The relations of the ore bodies within the ore formation to the diorites and dike rocks give evidence that the concentration of this ore has occurred subsequent to the intrusion of these rocks. It is certain that some of these eruptives are intrusives later than the Upper Marquette series, since they cut across the Ishpeming quartzite. Others of them appear to have yielded fragments to the Upper Marquette series, and therefore antedate these rocks. Finally, if the ore bodies had become concentrated before the Upper Marquette folding and erosion, their invariable positions above the impervious formations would be inexplicable. The folding would, perhaps, have left them as often below as above these formations. Taking all the facts together, it is highly probable that the concentration of all the ores occurred during and later than the folding and erosion subsequent to Upper Marquette time.

Surface waters bearing oxygen, passing downward through the Upper Marquette series or the iron-bearing formation of the Lower Marquette series, would decompose the iron carbonates with which they came in contact, and thus become carbonated. These carbonated waters would then be capable of taking other iron carbonates into solution. What proportion of the original iron carbonate still remained in the ore-bearing formation at the beginning of concentration is uncertain, but since it is still found in places sheltered from percolating waters, such as the deeper horizons of the iron formation, adjacent to and probably protected by diorite masses, it is probable that the quantity was very considerable. The oxides or carbonates of iron may also have been taken into solution through the agency of organic acids. These downward-moving waters would pass along and through the beds of the iron-bearing formation until they came in contact with an impervious substance. Here would also be carried other oxygen-bearing waters more directly from the surface. The union of these two currents would precipitate the iron oxide. The abundant waters traversing these ore-bearing localities would also slowly dissolve the silica, its place being taken by the ore. That this interchange actually does occur is known of the localities in which a detailed examination has been made, as, for instance, at Republic. It is probable that in the ore deposits associated with the soaprocks, the removal of silica is due in part to them. Originally diabases, they must have contained alkalies. The alkaline waters produced by their alteration would thus furnish a menstruum capable of taking the silica into solution. This desilicification of the iron-bearing formation by alkaline waters was many years ago suggested by Brooks[1] for a part of the Marquette district. Rominger[2] not only made the same suggestion in reference to the Jackson mine, but further held that the siliceous matter removed was replaced by oxide of iron carried by water solutions.

The percolating waters which carried material along the readiest paths to form the ore bodies, and which removed the silica, also helped to jasperize the upper part of the Negaunee formation, although this may have been partly done before Upper Marquette time. Whatever the time at which the work was done, the process seems to have been as follows: The quartz of the ferruginous chert was granulated by shearing. The upper part of the ore formation was more extensively traversed by solutions than the deeper-lying portions. It naturally follows that the ferruginous material was in part deposited about and through the minute particles of silica, reddening them and changing the material from white chert to red jasper. In some places this jasperization has extended deeper than in others, and, as already said, it sometimes abruptly stops at an impervious mass of soaprock.

One or two questions remain to be considered: First, why the ore is so frequently hard and specular along the contact horizon or in the jasper and is usually soft within the ferruginous chert; second, why the magnetites, when present, occur at the contact horizon.

An examination of the jasper associated with the hard ores shows that crystallized hematite and magnetite often occur in cavities formed by the removal of silica. In such geodal cavities these materials have been deposited in a granular crystalline condition. In the continuation of the process the silica was wholly removed and its place taken by the crystalline hematite and magnetite. The adjacent jasper also shows that numerous cracks and fissures have been filled with hematite or magnetite. The manner in which these veins of coarser crystallized material frequently cut across the finer-grained substances, which represent the iron oxides present before the concentration, shows conclusively that they are secondary infiltrations later than the last dynamic movement. The formation of the coarsely crystalline gran-

[1] Geol. of Michigan, Vol. I, p. 134.
[2] Geol. of Michigan, Vol. IV, p. 75.

ular hematite and magnetite thus appears to be connected with the abundance of iron-bearing solutious along the contact plane.

Oftentimes, however, the hard ores are of the brilliant micaceous or specular variety. This is sometimes called slate ore. In the hand specimen, composed of rapidly alternating layers of ore and silica, where the folding has been severe, micaceous ore is often found between the rigid bands of quartz. Along these ferruginous zones is seen all the evidence of slickensides, and the micaceous character. of the ore is seen to be due to the accommodation and consequent shearing which has taken place between the layers.

Now, the micaceous ore from the large deposits, as first suggested by Professor Pumpelly, gives the same evidence of shearing. When it is remembered that in the folding of thick formations accommodations and readjustments must occur, it is natural to suppose that these readjustments have taken place more largely at the contact between the Upper Marquette and Lower Marquette series than at any other one horizon, for this is emphatically the plane of weakness. Thus would be explained the finely laminated micaceous variety of ore. It is not impossible that shearing along the contact plane, with the heat developed, would be sufficient to change soft ore into micaceous hematite.

A close examination of these slate ores shows that they are composed of two parts, one of which has been sheared, the other being a crystalline hematite and magnetite, often with crystal outlines. This material fills the cracks left by the shearing, perhaps occupies the place of residual silica and welds the micaceous leaves together. Thus this granular ore was certainly deposited after the folding. How much was introduced during the folding it is impossible to say, for this part can not be separated from that present before the folding.

That it is easy to reduce hematite to magnetite is well known, and it is probable that the production of the granular infiltrated variety of this ore is due to the reducing character of some of the solutions which have passed down along the great contact plane of percolation where the magnetites are extensively found. This reducing power could readily be imparted by organic acids, and that some kind of reducing agent has been present is indicated by the veins of pyrite which are frequently associated with the magnetic ores.

The magnetite of the grünerite-magnetite-schist has been found to be due to an imperfect oxidation of the original iron carbonate. It is, however, doubtful if any considerable quantity of the magnetite of the greater number of worked ore bodies is directly of this derivation, although some of the lesser magnetite deposits appear to be an enriched grünerite-magnetite-schist. In these cases there is no particular difficulty in accounting for the larger part of the magnetite, but the same difficulty exists in explaining the imperfect oxidation of the infiltrated material as in the other instances.

PROSPECTING.

In considering the advisability of prospecting in any definite locality, the foregoing conclusions as to the relations of the iron ores may be of great assistance. These may be briefly summarized as follows: The iron ores are always confined to the iron-bearing formation. They always rest upon a relatively impervious basement. This may be a shale, a slate, a diorite, a dike, or two or more of these combined. Adjacent to the ores all of these formations are apt to be modified and impregnated with iron oxide, and are hence called soapstone or paint rock. The large ore bodies are found only when the impervious basements are in the forms of pitching troughs. These pitching troughs are particularly likely to bear unusually large ore bodies when the iron-bearing formation has been much shattered by folding.

In prospecting for the first class of ores, those that rest upon the Siamo slate, an outward swing of the boundary line between this formation and the iron-bearing formation should be sought, thus producing in the iron formation a plunging synclinal trough; or a trough may be formed by a combination of the slate with a cutting dike or an intersecting mass of greenstone, or a trough in the slate may be supplemented by an intersecting greenstone.

In the second class of deposits—those within the formation—the pitching trough is wholly formed by the intrusives. Here valleys of the iron-bearing formation, when nearly surrounded by an amphitheater of diorite, furnish a particularly favorable area. When the iron-bearing formation in the valley is the ferruginous chert, rather than the grünerite-magnetite-schist, the conditions are more favorable. Pitching troughs bottomed by soapstone may exist underground which can not be discovered at the surface, since, when the intersecting intrusive is of small size and has been transformed to soapstone, it is eroded as rapidly as the iron formation, and thus its existence is not discovered by outcrop or any topographic feature.

The third class of deposits, the hard ores, must always be prospected for near the contact of the Negaunee iron formation and the Ishpeming quartzite. As in the previous cases, the ore bodies are particularly likely to exist if the two are folded so that the contact forms a pitching trough, and if this be bottomed by soapstone the conditions are still more favorable for the formation of large deposits.

The general map (Pl. XIII) shows several extensions of the iron-bearing formation which have not been prospected. The arm running east of Palmer has been prospected along its south side, but as yet almost no work has been done along the north side. The exposures here are not sufficient to indicate the minor bends of the iron-bearing formation, but the break across the quartzite in sec. 28, T. 47 N., R. 26 W., suggests that there may be a north swing of the formation at this point; and if so, this would be a favorable point for exploration. Other favorable places may exist along the northern side of this syncline, but their exact positions can not be pointed out. The second eastward arm, running from the southeast corner of sec. 20, T. 47 N., R. 26 W., in a northeasterly direction, has not been explored at all. West of this arm is the great anticlinal dome of Teal Lake slate. This dome has been folded by minor rolls in an east-west direction, thus furnishing on the west side of the area a number of westward pitching synclinal troughs, in which are large deposits of ore. Doubtless the same conditions prevail on the eastern side, producing eastward pitching troughs, but here outcrops are not sufficient to accurately delineate the boundary lines; but while the existence of a swamp in secs. 3, 4, 9, and 10 makes the area difficult to prospect, the west side of the arm is a promising field for exploration. In the south side of sec. 3, near the north-south quarter line of the section, there is a ridge of diorite. This is also the end of the syncline which here plunges to the south. The junction of this diorite with the contact line between the Siamo slate and the Negaunee iron formation is a favorable point. Within the iron formation in secs. 10 and 15, the great mass of diorite forms a westward-facing amphitheater, and here in the southwest quarter of sec. 10 would seem to be a favorable place for exploration.

It is not impossible that a close magnetic survey with a dial compass and dip needle across the approximate boundary lines of the Siamo slate and the Negaunee formation, for these eastern arms, would enable the explorer to more accurately delimit the iron-bearing formation and to determine the probable positions of pitching troughs, if they exist, and thus point out the more favorable points. This attempt ought certainly to be made before money is spent in actual underground work. Exposures of these eastern arms are so infrequent that it is not certainly known that the iron-bearing formation maintains its pure nonfragmental character. If it be found that it contains interstratified or intermingled clayey material, this would be unfavorable to the development of merchantable ore deposits.

In the foregoing paragraphs it is not meant to imply that workable iron-ore deposits will surely be found in these eastern arms, but merely that the conditions are sufficiently favorable to warrant a search for them.

CHAPTER III.

THE UPPER MARQUETTE SERIES.

The general statement has been made that the Upper Marquette series first appears at Negaunee and at Palmer in two detached areas, reappears again at Ishpeming, and from this place rapidly widens out into a broad belt to the west, where it occupies the greater part of the area of Marquette rocks. It has also been said that this general distribution is due to the great north-south transverse anticline east of Negaunee.

Broadly considered, the Upper Marquette series was a great shale formation which has been subsequently modified to a greater or less degree. The lowest horizon of the series is, however, a conglomerate and quartzite, which marks the transgression of the sea. Replacing this in part in the west end of the area is a grünerite-magnetite-schist horizon. Following above this is the great slate formation, and near it is a horizon which originally bore a considerable quantity of iron carbonate, from which various ferruginous rocks have developed, and also small ore bodies. Finally, during Upper Marquette time, in parts of the district there was contemporaneous volcanic action, so that associated with the modified shales of the series is a belt of volcanics a number of miles long. As in the case of the Lower Marquette, later intrusives have penetrated the series at various places.

The Upper Marquette series is, then, structurally divisible into a lower belt of conglomerate, quartzite, grünerite-magnetite-schist, and associated rocks; a slate formation; and a belt of volcanics. The first will be called the Ishpeming formation, the second the Michigamme formation, and the last the Clarksburg formation.

SECTION I. THE ISHPEMING FORMATION.

The Ishpeming formation is so named because typical exposures of this formation surround the city of Ishpeming, and underlie it. For the eastern part of the district, and including the Ishpeming area, the predominant rocks are conglomeratic quartzites and quartzites. These are finely exposed at and adjacent to the Goodrich mine, and this rock will therefore be called the Goodrich quartzite. In the western part of the district, while quartzites are present, occupying a large part of the horizon of the Goodrich quartzite, and equivalent to it in age, is a peculiar schist which is typically exposed at the lower part of the Bijiki River, and it will therefore be called the Bijiki schist.

THE GOODRICH QUARTZITE.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY

The easternmost occurrence of the Goodrich quartzite is the Palmer area. From this village it extends east and west about 1½ miles, making a belt 3 miles long. From its western half, as a consequence of subordinate folding, a short belt projects to the southeast. Small isolated patches may also occur capping the Ajibik quartzite of the Ajibik Hills. The second subordinate area is near the town of Negaunee, north of the Jackson mine. On account of the close folding the boundary line of this area is very irregular. The chief area, as has been said, begins at Ishpeming. From this area a rather narrow belt extends in a course nearly due west to west of Michigamme. Another arm, of irregular width, swings to the south and southwest, then follows a general westerly course to sec. 20, T. 47 N., R. 28 W., where it swings to the northwest to Humboldt and Champion; thence it extends west, southwest, and south to the end of the Republic tongue in sec. 7, T. 46 N., R. 29 W., passes around the end of this tongue, and again swings to the northwest to sec. 20, T. 47 N., R. 30 W.; thence it swings to the west and south, forming another U similar to that about the Republic tongue.

The prominent exposures of the formation are usually near its base. At many places in passing upward the quartzite approaches a graywacke, is consequently softer, and therefore not so frequently seen. Exposures are particularly abundant in the Palmer and Negaunee areas, about the Ishpeming basin, and as far west on the southern tongue as the Fitch mine, sec. 24, T. 47 N., R. 28 W. For the last 3 miles of this distance it constitutes a rather prominent range. West of this place exposures are infrequent until Humboldt is reached. Here there are numerous exposures north of Mount Humboldt. At Republic are large and fine exposures. Many exposures are found in the northern belt south of the Michigamme and Spurr mines.

FOLDING.

Broadly considered, the Goodrich quartzite is folded into a great westward-plunging synclinorium, the eastern end of the U extending from Ishpeming southward. This eastern border of the formation comprises a series of reentrants and salients—reentrants where there are minor synclines, and salients where there are minor anticlines. On account of the flat dip, corresponding to the westward plunge of the syncline, the formation here occupies a broad belt. On the south side of the formation at one place the Goodrich quartzite and Negaunee iron formation are infolded and overturned, having northward dips. At this point the Ishpeming quartzite makes a tongue running east into the iron formation, being bounded both to the north and south by the rocks of the Negaunee formation, which dip in the same direction as the quartzite. The area at Negaunee is in general an east-west oval synclinal basin. Here again there is minor folding, so that the formation terminates both to the east and west in a number of fingers. At the west end of the Jackson mine the Goodrich quartzite and the Negaunee iron formation are folded into a set of isoclinal overfolds, so that a north south section passes three times from one formation to the other. The Palmer belt is another east-west synclinal basin, with a short arm extending to the southeast at one place, due to the appearance of a central anticline. The Republic tongue and that to the west are two closely compressed isoclinal synclines.

RELATIONS TO ADJACENT FORMATIONS.

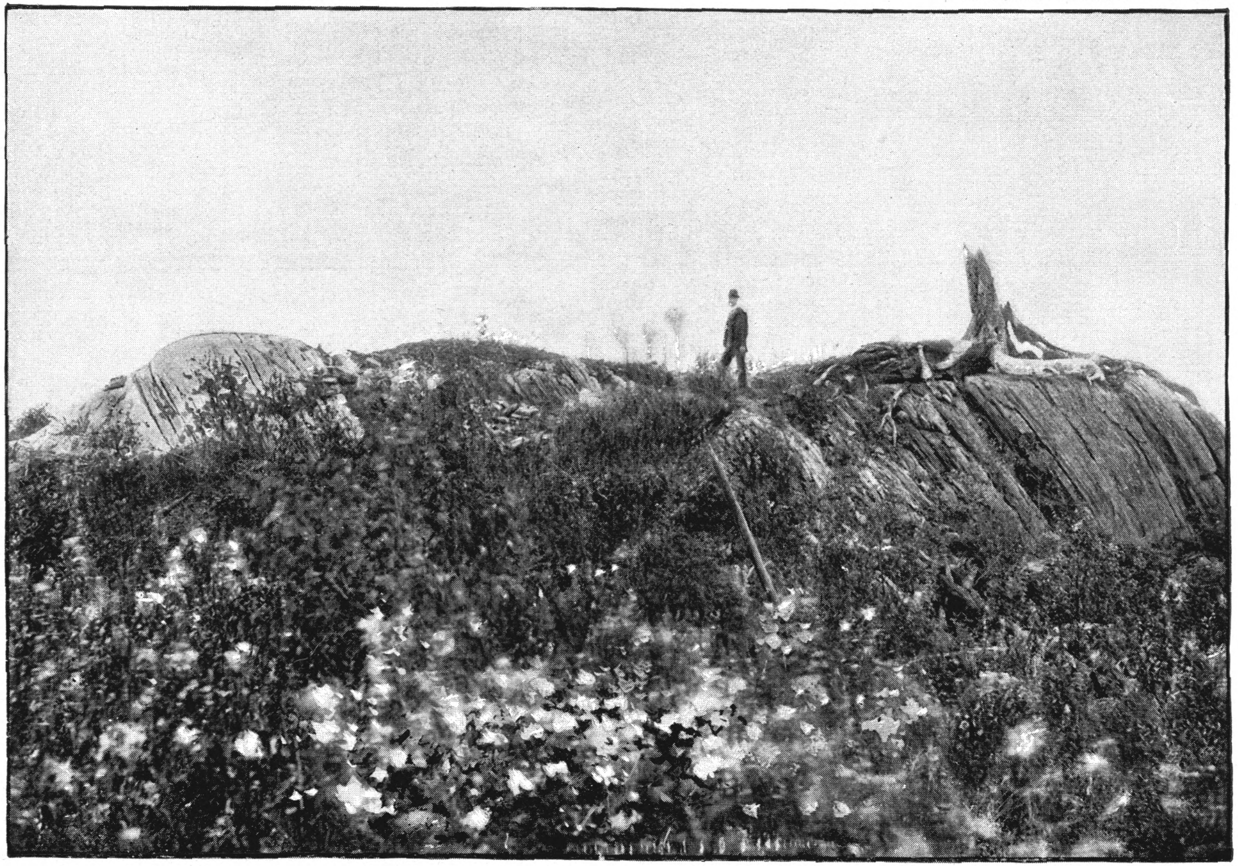
The relations of the Goodrich quartzite to the underlying Negaunee formation are so fully stated in connection with the latter and the general geology that they need not be here repeated. They are those of unconformity, and the advancing shore has formed a conglomerate at the base of the quartzite. As a consequence of mining development and the resistant character of this part of the formation, the conglomerate may be seen at scores of localities lying upon and cutting across the bedding of the underlying formation at a greater or lesser angle (figs. 18 and 19).

Where erosion has cut through the Negaunee formation, as on the Ajibik Hills northeast of Palmer, the basal conglomerate rests upon the Ajibik quartzite, and derives the majority of its fragments from it. Where the latter formation has also been cut through, as apparently it has been south of Palmer, the material is largely derived from the Basement Complex. This fact, that the Goodrich quartzite thus comes in contact not only with the Negaunee formation but with inferior formations, shows that the unconformity between the Upper and Lower Marquette series must be very considerable.

By a dying out of the coarse fragmental quartz and the appearance of clayey material the quartzite by gradation passes into the Michigamme formation for much of the district. This gradation is usually not rapid, and hence the location of the boundary line between the two is somewhat arbitrary. At the western end of the district the quartzite is very thin, and the formation passes quickly upward into the grünerite-magnetite-schists of the Bijiki horizon. (Pl. XXIV.)

PETROGRAPHICAL CHARACTER.

Macroscopical.—A conglomerate is usually at the base of the Goodrich quartzite. The character of the conglomerate depends upon the subjacent formation, the larger portion of the detritus in each case being derived from it. As has been stated, this inferior rock is usually the Negaunee formation, and at the base of the Goodrich quartzite is ore, recomposed ore, or ore, chert, jasper, and quartz conglomerate. At a few places the subjacent rocks belong to the Archean, and here the great variety of materials constituting this complex are predominant in the conglomerate. At various places—as, for instance, in the great



CONFORMABLE EXPOSURE OF GOODRICH QUARTZITE AND BIJIKI SCHIST, WITH GRADATION ZONE BETWEEN, NEAR MICHIGAMME, MICHIGAN.

conglomerate at and immediately south of the village of Palmer—there are abundant quartzitic, granitic, and schistose bowlders, derived from the Archean, and also abundant jaspilite fragments from the Negaunee formation. On the Ajibik Hills small patches of the Goodrich quartzite rest on and have derived fragments from the Ajibik quartzite-schists and quartzites. As these two quartzites in their ordinary characters are very similar, it is only by the closest study that it is possible to separate them. On the map these hills are colored as Ajibik quartzite.

The basal conglomerate, of varying thickness, grades up into ordinary quartzites, which, however, are apt to contain a good deal of chert and jasper in minute fragments. The higher horizons of the quartzite are usually feldspathic. Frequently the shearing action due to the folding was so severe as to partly or wholly destroy the fragments of ore and jasper, making the rock a schist-conglomerate or schistose quartzite. This change is complete at the places where the close infolding which has been spoken of occurs, as at the Jackson mine, at Humboldt, and in the Republic trough. In the most extreme phase it is difficult to discriminate the sheared and recomposed ore and jasper conglomerates from the original jaspilite. In passing from the least altered to the most altered phases, we find first flattened pebbles, then those which are elongated into layers, and finally those in which are alternating layers of different thickness, which simulate in a remarkable degree original lamination.

In the case of the nonconglomeratic recomposed jaspers, the rocks are not unlike the original formation, although a close examination usually shows a difference. Ordinarily, large fragmental grains of quartz are seen; flakes of mica are often present, and the banding is less distinct than in the original jasper.

Under the subject Negaunee Iron Formation the development of ore bodies within the Ishpeming formation has been mentioned. This usually occurred at places where the detritus was rather fine grained, and thus contained no large fragments of chert and jasper. As conspicuous localities for the occurrence of these recomposed ore-bodies may be mentioned the Volunteer mine, the Barron, the Humboldt, the Champion, part of the Jackson, and part of the Michigamme and Spurr. As a consequence of the intense shearing which the formation has undergone, numerous cracks have been developed, and minute spaces were also left between the sheared laminæ and between the individual particles. Where the rock has been enriched so as to become an ore, as has been before explained, secondary magnetite has infiltrated. The detrital sheared micaceous hematite is usually easily discriminated from the crystal outlined secondary magnetite. While a considerable percentage of the iron oxide of the ore was present as detritus, in no case does it appear that the material was rich enough for merchantable ore before this secondary concentration, and often the secondary magnetite and its alteration product, martite, are the predominant constituents of the ore.

Microscopical.—With the microscope, the basal conglomerate resting on the Ajibik quartzite is found to have a background consisting of quartz grains set in a more or less abundant sericitic, cherty, and iron-impregnated matrix. This matrix may be so abundant as to separate the fragmental grains, or may be sparse. In this background are found complex fragments of quartzite, the individual grains of which are rounded and in which are fragments of sericite-slate and schist, all identical with these rocks in the Ajibik quartzite.

In the Repubilc trough, where the Ishpeming formation rests directly upon the Archean, the schist-conglomerate found at its bottom has as a matrix a micaceous quartz-schist. In certain varieties feldspar is abundant in the background, when it becomes a mica-gneiss. In this background are oval or ribbon-like areas or granules of quartz or of feldspar, which represent the sheared pebbles of the conglomerate. Occasionally these pebbles contain both quartz and feldspar, and represent complex fragments derived from the granite. The feldspar is usually shattered, and along the crevices mica and quartz have developed. Frequently the residual-feldspar and the secondary quartz and mica form an interlocking mass. Were it not for the pebble-like areas these rocks would be regarded as completely crystalline schists.

When the Ishpeming formation rests upon the Negaunee formation there are three main phases of material: (1) Chert and jasper conglomerate, (2) recomposed jasper, and (3) ore.

The chert and jasper conglomerate may have a sparse or an abundant matrix. In the first case the matrix consists of small, simple, fragmental grains of quartz, complex particles of ferruginous chert and jasper, and iron oxide. In passing to the less strongly conglomeratic phases, the matrix is a continuous ramifying mass, which contains the separate pebbles and bowlders. This matrix may be composed chiefly of any one of the substances, iron oxide, chert, jasper, or quartz, or of any combination of them. Not infrequently some secondary muscovite has also developed. Often the quartz grains are enlarged. In all cases the simple quartzes show undulatory extinction and fracturing, and in these and other crevices secondary hematite and magnetite have been deposited. When the shearing was intense, the fragments of chert, jasper, and quartz were crushed into thin layer-like areas, and in this case the slide of the recomposed rock differs but little in its appearance from the original jaspilite. Accompanying this granulation of the ore, chert, and jasper, the hematite was also sheared into brilliant, finely laminated, micaceous or silky fibrous hematite. Flakes of muscovite are usually seen. The secondary magnetite and hematite are easily discriminated from the sheared micaceous hematite by having crystal outlines. This infiltrated material is frequently present in very large proportion, filling all the interspaces between the original particles and the cracks formed within the fragments. In some cases the secondary hematite and magnetite have such relations to the quartz grains as to show that the silica was actually dissolved and replaced by the iron oxide. To what extent this occurred when the rocks are much sheared it is difficult to say, but in the little-altered phases we find crystals of hematite and magnetite which not only pass to the borders of the cores of the original grains, but beyond them. There seems to be some relation between the solution of silica and the deposition of magnetite; that is, when the conditions are favorable for the deposition of magnetite they are also favorable for the solution of crystalline quartz. The most perfect phases of recomposed jaspers have very much the same appearance as those of the original jasper formation, but when examined with a low power the overlapping lenticular leaflets of the sheared chert and jasper fragments are seen, and a high power shows in some cases a micaceous element which is almost universally absent in the original formation. In the less perfect phases of the recomposed jaspers their genesis is more plainly indicated by the presence of coarse-grained quartzose material, not derivable from the immediately subjacent formation; but even in such cases these quartzes were often granulated into jasper-like material.

By a disappearance of the siliceous element and an increase of the secondary hematite and magnetite, the recomposed jasper passes into magnetite-hematite-schist, or slate ore. Macroscopically these ores generally show a peculiar gray color, and in thin section they are usually easily separated from the ores of the Negaunee formation by the presence of brilliantly polarizing flakes of muscovite and of occasional particles of fragmental quartz.

The conglomerates, recomposed jaspers, or recomposed ore, by a lessening supply of the chert, jasper, and iron oxide, grade upward into the quartzites. In the purer phases these quartzites consist mainly of well-rounded simple fragments of quartz, which are frequently enlarged, but with these are usually complex particles of chert and jasper. The quartz grains generally show strong pressure effects by undulatory extinction or fracturing in a complex manner. This fracturing is in certain cases in a rectangular system corresponding to the maximum and mean pressure and shearing. In other phases there is an abundant matrix, composed of finely crystalline quartz, with sericite, biotite, and chlorite, in which the large fragmental grains of quartz are set. By an introduction of feldspar the quartzites pass into feldspathic quartzites, and from these to the graywackes of the Michigamme formation. In the less pure quartzites, sericite, biotite, and chlorite frequently developed abundantly from the clayey background.

In the more sheared phases of the quartzite, and particularly in the Republic trough, the rocks are micaceous quartz-schists. Usually the grains of quartz still show a roundish appearance, but they interlock intricately, and show no evidence of original cores. Int he finer-grained, most sheared kinds, the background is a finely granular interlocking mass of quartz. Feldspar is plentifully associated with the quartz in a number of cases. Between and wrapping around the larger grains abundant muscovite is found. In some of the rocks muscovite is a chief constituent, and these may be called muscovite-schists. Muscovite-biotite-schists and biotite-schists are also associated with the quartz-schists. These are, in nearly all aspects, like the more crystalline rocks of the Michigamme formation. In a few places feldspar is a chief constituent of the background, when the rocks become mica-gneisses. Various accessory minerals, such as chlorite, epidote, and zoisite, are found in the quartz-schists, mica-schists, and mica-gneisses.

At various localities there are exceptional varieties of rocks which belong to the Ishpeming formation, but these will not be considered here. Their characters will be given in the final report, where the localities are considered in detail.

THICKNESS.

The thickness of the Goodrich quartzite is variable, and no average estimate can be given, as it is not sharply delimited above. The best known locality to determine its thickness is north of the Saginaw mine, where it has a surface width of about 1,800 feet and an average dip of probably not less than 60°. This would give a thickness of about 1,550 feet. Since the transgression horizon here rapidly cuts across the iron formation, and a short distance to the west reduces it to a narrow belt, it is probable that this thickness is much beyond the average of the formation, even for the Ishpeming area, and that it is several times as great as in the western part of the district.

THE BIJIKI SCHIST.

The second division of the Ishpeming formation is the Bijiki schist. The rock is given this name because typical exposures of it occur near the mouth of Bijiki River. They were regarded by Brooks as an anthophyllitic schist.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

This horizon has three narrow belts. The northernmost one extends, with frequent exposures, from the west end of the district just south of the Goodrich quartzite, to sec. 28, T. 48 N., R. 29 W. The belt may extend somewhat farther to the east than this, but there are no exposures. The second belt is a short distance south of the first. It runs along the northern side of Michigamme Lake to a point northeast of Champion. The third belt extends from the southern extremity of Michigamme Lake to Champion, and is north of the southern belt of Goodrich quartzite. The Bijiki schist thus appears to be confined to the west end of the district. In the time scale it must be equivalent to a part of the Goodrich quartzite to the east. When the Bijiki formation appears the Goodrich quartzite becomes an exceedingly narrow belt, too small to be shown on Pl. XIII, hence the two are mapped together as the Ishpeming formation.

The rock is of a resistant character, and for the areas outlined there are numerous exposures. South of Michigamme and Spurr it makes conspicuous east-and-west ridges just north of the railroad. For most of the length of Lake Michigamme the southern border of the central resistant belt forms the northern lake boundary. However, at two or three places, the schist was cut through and the lake shore follows the softer formation behind. In these cases the Bijiki schist constitutes headlands surrounded on three sides by water. In the same way the convex southeastern shore of Lake Michigamme is limited by the southern belt of this schist. At various places erosion encroached upon the belt, but the rock is so resistant that the lake shore nowhere cuts entirely across the formation.

FOLDING.

The belts adjacent to the Goodrich quartzite owe their position to their being the next higher formation in the general synclinorium of the district. The central belt is due to a subordinate anticline which rises high enough to expose the Bijiki schist, but erosion has not reached a lower horizon, and thus a section across the area, including the three formations, includes two synclines with a central anticline.

PETROGRAPHICAL CHARACTER.

Macroscopical.—The Bijiki schist is a banded grünerite-magnetite-schist. Associated with this rock are also phases which approach the Michigamme slate above and the Goodrich quartzite below. These are usually gradation phases, and occur upon the outer parts of the belt. (Pl. XXIV.) The grünerite-magnetite-schists consist of alternate bands composed mainly of the three minerals, quartz, grünerite, and magnetite, and while in any single band one of these minerals may be predominant, the other two are usually present. The rocks are gray or green, and in their purer phases they differ chiefly from the grünerite-magnetite-schist of the Negaunee formation in their exceeding toughness. It is with great difficulty that the rock is broken into pieces parallel to the stratification, so firmly are the different plates bound together by the long grünerite needles, but it is comparatively easy to break the rock across the bedding. This peculiar toughness and the more coarsely crystalline character of the grünerite are the chief points which distinguish it from the similar rock of the Negaunee formation.

Microscopical.—The kinds of the schist free from clastic material consist of intricately interlocking grünerite, magnetite, and quartz, with more or less of hematite. The different materials may be uniformly intermingled, but more commonly each becomes alternately predominant, and this gives the rock a banded appearance. Occasionally the amphibole has a green color, and with this is a decided pleochroism, perhaps indicating that it is common hornblende. Not infrequently the same amphibole individual is composed in part of the hornblende and in part of the grünerite. In different individuals and slides the two show the greatest variety of intergrowths. In one or two instances, near the top of the member, siderite is an important constituent, constituting a matrix in which the other constituents are set. In other cases, at lower horizons, a little residual siderite is seen, which is surrounded and penetrated by grünerite or hornblende and magnetite, strongly suggesting that these minerals, with the addition of silica, have developed from the siderite. In passing toward the base of the horizon rounded and enlarged grains of fragmental quartz appear within the completely crystalline interlocking grünerite, magnetite, and quartz. Continuing toward the Goodrich quartzite, we have a fragmental quartzose background in the matrix of which grünerite and magnetite have developed. In both the pure and the impure phases a good deal of garnet appears. It is possible that a part of the grunerite and magnetite are detritus derived from the Negaunee formation, but the extraordinary likeness of the Bijiki schist to the grünerite-magnetite-schist produced by metasomatic processes from iron carbonate, the presence of siderite in the formation itself, the relations of this siderite to the grünerite and magnetite, the absence of any fragmental appearance, all suggest that the rock developed out of an original sideritic slate, similar to that of the Negaunee formation. It is not improbable that the development of the grünerite-magnetite-schist, both in the Upper Marquette and Lower Marquette series, was a simultaneous process, occurring during and after the Upper Marquette folding.

RELATIONS TO ADJACENT FORMATIONS.

It has been said that the Goodrich quartzite grades rapidly upward into the Bijiki schist. The Bijiki schist in turn grades into the Michigamme formation, the intermediate zone again being half fragmental. Belonging with or immediately above the grünerite-magnetite-schists, in the western part of the district, are the ore deposits of the Upper Marquette series. These ore bodies appear, however, to be rather within the slates than to belong with the grünerite-magnetite-schist; but if exposures were sufficiently numerous, it might be possible to map in the Upper Marquette series a continuous iron-bearing formation which would include these ore bodies and the grünerite-magnetite-schists, thus making the latter rocks the lowest horizon of this ore formation.

THICKNESS.

The formation varies from a considerable thickness to disappearance, and, as in the previous cases, it is impossible to give an accurate estimate. At some places it apparently has a surface width of 600 feet, with a dip varying somewhat, but perhaps averaging 60°. This would indicate a maximum thickness of about 520 feet.

SECTION II. THE MICHIGAMME FORMATION.

The name Michigamme is given to the upper slate and mica-schist because on the islands of Michigamme Lake and on the mainland adjacent to the shore occur extensive exposures of this formation.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The Michigamme formation is mainly in a single great area. Beginning west of Ishpeming, it sweeps westward as a broad belt to near Humboldt; here it becomes somewhat contracted, and east of Michigamme Lake it is divided into two belts, a narrow northern belt between the two zones of Bijiki schist, and a broader southern belt, which includes the gréater part of Michigamme Lake and the country to the westward. This belt widens out over a broad area, and occupies a great expanse of country in the large district of Algonkian rocks at the west and south part of the area covered by the present report. From this broad area two arms project, forming the centers of the Republic and Western tongues. At and east and west of Humboldt is a southern lenticular area about 6 miles long.

As this formation was originally a shale or grit, where it has not been much altered the exposures are not prominent, and the area, as a whole, is one of rather feeble relief, occupying lowlands between the ridgy country of the formations both to the north and south. This is particularly the case from the eastern extremity of the area to Lake Michigamme. At Lake Michigamme and to the south and west the formation has been much more metamorphosed, becoming a mica-slate, a mica-schist, or a mica-gneiss, and here, on account of the increased resistant character, the exposures are numerous and conspicuous, especially on the southern side of the west arm of the lake and upon the islands to the east. In the Republic tongue the schist, being softer than the lower formations, is followed by the Michigamme River.

FOLDING.

Broadly considered, for most of the area the Michigamme formation is in a great syncline. This syncline is, however, very complex, and there are many subordinate anticlines and synclines. East of Michigamme Lake one of these anticlines is of sufficient importance to bring the Bijiki schist to the surface, and thus to divide the Michigamme formation into two synclines, the southern one of which is the more important. Another probable anticline is indicated by the iron ore pits in secs. 29 and 35, T. 48 N., R. 29 W., as it is thought that the ferruginous horizon belongs near the base of the formation. The Republic and Western tongues are both isoclinal synclines. When the exposures are examined in detail, it is often found that the secondary anticlines and synclines have upon them tertiary folds, and upon these are folds of the fourth order, and so on to microscopic plications; so that in many places the rocks are minutely implicated. This is particularly well seen in the schist at Michigamme Lake.

PETROGRAPHICAL CHARACTER.

Macroscopical.—The rocks of the formation comprise three main varieties—little-altered slates and graywackes, ferruginous slates and graywackes, and mica-schists and mica-gneisses. The first two of these occur chiefly in the area east of Michigamme Lake, and the last in the Michigamme Lake district, although representatives of the first two are found along the northern side of the Michigamme formation to the western limit of the area considered. The mica-schists are also found along the southern part of the belt several miles east of Clarksburg. It can not be said that these divisions are in any way stratigraphical, unless it be true of the ferruginous phases, which appear to occupy a somewhat persistent horizon; but these rocks are not so well defined that they can be mapped as a separate formation.

The slates and graywackes differ from each other chiefly in coarseness of grain, the two often being interlaminated in the same exposure or ridge. There are all gradations, from the aphanitic, black shales or slates to a graywacke so coarse as to approach a quartzite, or, in one case, a conglomerate. The rocks vary in color from gray to black. Where they are fine-grained they usually have a well-developed, slaty cleavage, and are often carbonaceous, ferruginous, and pyritiferous. In some places the amount of carbon is so great as to give a black streak. A portion of the carbon appears to be in the form of coaly substance, but much of it has been transformed to graphite. When broken apart parallel to the cleavage the graphite is frequently in a lustrous form, due to movements parallel to the parting. The pyrite is in detached crystals, and in laminæ parallel to the parting. The least altered of these rocks could properly be called shales or grits. In places where they are more altered, the former pass into mica-slates, and from these into the mica-schists. The ferruginous slates and graywackes contain a good deal of iron. In the least-altered phases this iron is largely in the form of siderite, and thus the rock is a sideritic slate. Rarely the siderite becomes the predominating constituent, and in this case the rock is similar to the sideritic slates of the Negaunee formation. As a consequence of weathering and metasomatic changes, ferruginous slates, ferruginous cherts, and grünerite-magnetite-schists have developed from these sideritic slates. In the few localities where the ferruginous material was very abundant small ore bodies also have formed. Such are known at three places north of Champion and at one south of Spurr. Pits also occur in the south halves of secs. 29 and 35, T. 48 N., R. 29 W. These ores differ from those of the Negaunee formation in that the iron oxide is largely limonite and in that the associated rocks contain much carbonaceous and graphitic material. The ferruginous phases are particularly prevalent just above the Clarksburg volcanics and the Ishpeming formation; i. e., a short distance above the formations which are immediately subjacent to the Michigamme formation. All of the pits may and probably do belong to the same horizon. If this be true, the central belt is near the crest of an anticline, which rises high enough to bring this low ferruginous horizon of the formation to the surface. The foot wall of the ore bodies is, so far as observed, the impervious fragmental Michigamme slate. The ores and peculiar associated rocks therefore appear to be in bunches or in lenses in the carbonaceous slates, strongly suggesting that the abundant organic material had to do with the deposition of the iron compounds.

At Lake Michigamme, it has been said, mica-schist is abundantly developed in its typical form. This mica-schist, while a completely crystalline rock having well-developed schistosity, still shows in places, when closely examined, the original bedding, and an alternation of coarse and fine material such as occurs in the slates and graywackes to the east. The schistosity varies from parallel to perpendicular to the bedding, usually being at some intermediate angle. Where the schists are completely crystalline, garnet, staurolite, chlorotoid, and andalusite are often plentifully present.

In the most coarsely crystalline kinds the rock is sometimes veined throughout with a granitic-looking material, and feldspar has also abundantly developed within the rock. The gneiss is pegmatized through and through, as though the material, either as a magma or in the form of a solution, had penetrated the joints, the partings parallel to the laminæ, and also the interspaces between the constituent particles, and had in these places produced quartz and feldspar. A close examination shows that many of the apparent granitic veins are but the coarser beds strongly pegmatized. The pegmatized areas grade into the ordinary mica-schist. It was concluded that the pegmatization was not the result of an igneous injection from an extraneous source, particularly as there are no known granite intrusives within this part of the Upper Marquette series. The facts seem rather to be explained by water action. The whole rock must have been permeated by hot solutions, from which the new minerals separated in the interspaces left by the folding.

If this explanation be correct, the rock is one to which the term metamorphism is still applicable. Why the rocks of this part of the formation have been so thoroughly metamorphosed and those to the east comparatively little affected has not been certainly determined. The beds are intensely plicated. Such plication involves a large amount of readjustment of the layers over one another and within the layers themselves; that is, the shearing was exceedingly severe. During this time of folding, by the decomposition of fragmental feldspar into quartz and mica, the development of new feldspars in some places, and the granulation of the coarser crystalline quartz, the rock changed into a mica-schist or a mica-gneiss.

Microscopical.—The slates and graywackes consist mainly of fragmental quartz and feldspar, set in a clayey and micaceous matrix. Occasionally other fragmental constituents, and especially mica, are found. In the cases of the finer-grained slates, the clayey matrix is predominant. In the coarser-grained graywackes the plainly fragmental material is predominant. In the latter we often have closely fitting grains of quartz, some of them well rounded and enlarged, with few of feldspar, set in a sparse matrix. This rock approaches a quartzite. The fragmental constituents generally show pressure effects, the larger grains being broken into two or more fragments, or cut by fine cracks, which cause undulatory extinction or fracturing, sometimes in a rectangular manner. The fragmental grains of feldspar have largely decomposed, and quartz, biotite, and chlorite have developed from them. In the clayey background there have developed many minute flakes of biotite, sericite, leaflets of chlorite, and sometimes needles of actinolite. These usually do not have a parallel arrangement. More frequently than not there is also present a greater or lesser quantity of ferrite. Sometimes crystals of tourmaline also occur.

In proportion as the feldspar is decomposed and the quartz is granulated, the rocks approach the mica-schists, an intermediate phase being represented by the mica-slates. These still show evidence of their fragmental origin, occasional fragmental grains of quartz being seen, some of which are enlarged. Many of these fragmental grains are easily separable from the newly developed quartz, showing as they do undulatory extinction or fracturing. The quartz grains begin also to show an arrangement with their longer diameters in a common direction. The folia of biotite also have a parallel arrangement. In a further stage much of the quartz has been granulated, and the feldspar is largely replaced by secondary mica and quartz.

These mica-slates on the one hand grade into the ordinary slates and graywackes step by step, and on the other hand, by greater alteration, they pass into mica-schists. When the process of metamorphism is complete, the fragmental quartz grains have become wholly granulated by the shearing, which has kneaded the rock throughout, each folium having moved differentially in reference to those above and below it. The fragmental feldspar is wholly changed into quartz, mica, and chlorite. The folia of mica have developed with their longer axes in common directions. In proportion as the dynamic effects are severe, sericite and muscovite become prominent with the biotite. In place of the fragmental rock, we have now a completely crystalline mica-schist.

The details of the processes of development of these schists will not be here described, but they are similar to those given for the development of the mica-schists in the Penokee series.[1] There has, however, been the difference explained above, that shearing has played a much more important part in the case of the mica-schists of the Marquette area. As a consequence, the schists are sometimes strongly foliated. In the more completely crystalline schists a large amount of garnet, staurolite, andalusite, and chlorotoid have developed. These minerals include large quantities of the prior quartz. They show no evidence of strain, and they are believed to have developed in the quiescent stage, after dynamic action had ceased, but while its heat was still furnishing hot solutions which bore abundant mineral material.

[1]The Penokee Iron-bearing Series of Michigan and Wisconsin, by R. D. Irving and C. R. Van Hise; Mon. XIX, U. S. Geol. Surv., pp. 332-343.

By the formation of the secondary feldspar, probably by the same process, both within the crevices and between the grains, quartz-mica-feldspar rocks or mica-gneisses have developed. These mica-gneisses have an interlocking granitic-appearing background, composed of quartz and feldspar in about equal abundance. That the rock was originally fragmental is indicated only by occasional roundish grains of quartz and feldspar, but it is always difficult to determine certainly what part of the quartz and feldspar is original and what part a secondary development. Both the original and secondary feldspars are stained with limonite and have decomposed to a greater or lesser degree into chlorite, biotite, and quartz. Biotite is the predominant micaceous mineral, but muscovite is present, and chlorite is abundant. Magnetite is also present in numerous crystals, and a small amount of hornblende is found. The veins cutting the gneisses are composed mainly of iron-stained feldspar, with, however, a good deal of chlorite and quartz. This feldspar, which is beyond all question secondary, is identical in its appearance with that contained throughout the rock. In the mica-gneiss are curious black concretionary-looking areas, which in thin section are seen to be essentially the same as the remainder of the rock, except that they contain numerous large crystals of hornblende and much zoisite. Each of the hornblende individuals includes many of the other mineral particles, and in their development they appear to be analogous to the staurolite and garnet.

The occurrence of these mica-gneisses within the Michigamme formation is of great interest as proving the development of this kind of rock from a clastic. In almost every respect the most crystalline of these mica-gneisses are similar to many mica-gneisses of the Basement Complex. The only difference between the two is that in the Michigamme area these crystalline forms may be traced by gradations to phases in which the fragmental characters are clearly apparent.

The purest and least-altered phase of the ferruginous rocks is sideritic slate. This is a fine-grained gray rock, composed almost wholly of siderite, which upon the weathered surface exhibits a reddish-brown color as the carbonate passes into iron oxide. From these ferriferous carbonates there have developed ferruginous slate, ferruginous chert, jasper, grünerite-magnetite-schist, and iron ore, the processes and results being indentical with similar rocks from similar materials in the Negaunee formation. (See pp. 566–576.) The description of these processes will therefore not be here repeated.

Certain minor differences separate these rocks from those of the Negaunee formation: The grüneritic rocks are finer-grained, the iron oxide is largely limonite, and in all phases of them carbonaceous material is abundant.

The amount of pure nonfragmental material is subordinate, but because of its character it is not unimportant. There is in this formation a much larger quantity of material intermediate between clastic and nonclastic sediments. In some places the fragmental and nonfragmental material is largely concentrated in alternate bands. In other places the two are intermingled. When least altered, these intermediate rocks may have a background consisting of siderite and cherty quartz, with some ferrite, which contains numerous well-rounded fragmental grains of quartz and feldspar. As the metamorphosing processes set in, the siderite goes through the same set of transformations as when it is alone, and the same is true of the fragmental material, so that there results a great variety of rocks. When the processes are chiefly metasomatic the siderite changes to ferrite, and ferruginous graywackes, ferruginous slates, cherty graywackes, and cherty slates are produced. In a common variety a ferrite background contains the clastic constituents. If at the same time the feldspar alters to biotite and chlorite, the slates are biotitic and chloritic. When the dynamic effects are stronger, grünerite and magnetite develop from the siderite, the secondary mica has a parallel arrangement of its folia, and the quartz is arranged with its longer axes in a common direction, or is granulated, so that there result hematitic and magnetitic mica-schists, grüneritic mica-schists, etc. At different places there are all gradations from the least to the most metamorphosed varieties, and from those which originally consisted wholly of fragmental material to those which consisted wholly of nonfragmental material. In the first case the peculiar rocks of the iron formation have been formed; in the second case the mica-schists and mica-gneisses have formed. Between one extreme and the other, there is every gradation.

RELATIONS TO UNDERLYING FORMATIONS.

It has already been said that the Michigamme formation grades slowly down into the Goodrich quartzite or into the Bijiki schist, and that therefore the line of separation between them is more or less arbitrary.

THICKNESS.

The thickness of this formation must be considerable, as it covers a wide area, but it is impossible, on account of the subordinate folding to which it has been subjected and the extensive development of slaty cleavage and schistose structure which cut across the bedding, to make even an approximately accurate estimate. It is possible that within the area described its thickness may not be more than 1,000 to 2,000 feet, or it may be much more.

SECTION III. THE CLARKSBURG FORMATION.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

Running both east and west from Clarksburg is a broad belt of rocks consisting mainly of surface volcanics. The western extremity of this belt is north and west of Champion. Passing to the east, it becomes wider for some distance, narrows again, and swings to the southeast, toward Clarksburg. Again widening, in secs. 8, 17, and 20, T. 47 N., R. 28 W., its width becomes about 1½ miles. From this place it swings to the east again and becomes gradually narrower, finally disappearing north of Stoneville. It is noticeable that where the belt has its maximum width the underlying formations have a great southward swing, and that as the Clarksburg formation dies out both to the east and to the west, they take their normal course. The oval outline of the area is also noticeable, it having a great width 2 miles southeast of Clarksburg and narrowing to the east and west, its total length being about 10 miles.

Throughout the area and especially in its central portions, there are very numerous large exposures which rise in bluffs from the generally low, level, and often marshy area separating the higher lands.

PETROGRAPHICAL CHARACTER.

The rocks composing the Clarksburg formation vary from massive greenstones to rocks which are plainly volcanic conglomerates. On the freshly fractured surface some of the phases appear to be completely massive, but upon the weathered surface they show a peculiar pitted weathering, very characteristic of tuffs. The conglomerates in their most massive varieties show no bedding whatever, but to the east and west of the central area some indications of bedding appear. It is as though tuffs had fallen in water and had been more or less rearranged by it and mingled with ordinary sedimentary material. Still farther east and west from the center the bedding becomes plainer, and the amount of water-deposited material increases, until finally the formation dies out, being replaced by the Michigamme formation. In the upper and outer parts of the area, true sedimentary slates are interlaminated with the volcanic fragmentals.

Lithologically the rocks of the Clarksburg formation comprise diorite-schists, hornblende-schists, biotite-hornblende-schists, and many peculiar phases of rocks intermediate between the fragmental slates and these typical igneous phases. To describe in detail the many complicated phases would too greatly extend this preliminary paper, and therefore they will not be further considered.

RELATIONS TO ADJACENT FORMATIONS.

From the center of the area for some distance west this belt rests directly upon the Ishpeming formation; indeed, the Ishpeming formation in many places appears to grade up into the volcanics, although at the center of the belt there seems to be an abrupt change from one to the other. Before Humboldt is reached the belt swings north of the Ishpeming quartzite, a band of the Michigamme slate appearing between the two. As Champion is neared the volcanics are again found upon and associated with the Ishpeming quartzite. West of Champion the belt once more passes into the horizon of the Michigamme slate. To the east of the center of the area for some distance the Clarksburg formation comes immediately above the Ishpeming formation, but finally, as at the west, it runs up into the horizon of the Michigamme slate. So far as can be ascertained, the formation grades upward into the Michigamme formation, and its boundary line is therefore somewhat arbitrary.

The explanation of this exceptional formation is believed to be as follows: In Upper Marquette time, shortly after the deposition of the Ishpeming quartzite had begun, and perhaps in connection with the movement which inaugurated the Upper Marquette deposits, a volcanic outbreak occurred, with its main center somewhere in secs. 17, 18, or 20, T. 47 N., R. 28 W. From this submarine volcano materials were extruded until, by upbuilding, an island was formed. Lavas were poured out; tuffs fell upon these, and they also dropped upon the water beyond the confines of the island. Near the shore, lavas, tuffs, and sedimentary material became intermingled in the most irregular manner. The influence of the volcano gradually extended, but with lessened vigor as the distance from it increased, so that sedimentary material became more and more prevalent, and the belt of volcanic origin became thinner and thinner. Apparently there were also at least two subordinate volcanoes, one at Champion and the other north of Stoneville. This probability is indicated by the abundant masses of typical volcanic tuffs at these two localities, by the local widening of the volcanic belt, and by the appearance of a belt of the Michigamme slate between the Clarksburg formation and the Ishpeming formation between Champion and Humboldt. Apparently the Clarksburg and Champion volcanoes formed at about the same time, but their influence did not reach to the middle of the intervening area until in the time of the Michigamme slate.

It therefore appears that the Clarksburg formation displaces the upper part of the Ishpeming formation and the lower part of the Michigamme formation in a part of the district, and was therefore formed during the time in which these parts were deposited.

The fact that the lower formations bend to the south in an unusual manner southeast of Clarksburg strongly suggests that during the time that the mountain mass of volcanic material was being built up simultaneous sinking was going on, due, doubtless, to the weight of the mountain mass. The effect of this sinking is most marked near the volcano and is of less and less importance as the volcano is left in the distance. The great width and thickness of the volcanics in the center of the area are equivalent in time to a much smaller thickness of ordinary sediments, and thus is explained the gradual diminution of the width of the belt both east and west of the center until it finally disappears, and it is not impossible that the thickness of several thousand feet of volcanics which occurs southeast of Clarksburg is to be equated with a few hundred feet of the ordinary sediments of the district.

It is to be supposed that the volcanic material from the main volcano had a circular or oval distribution, and therefore we would expect to find the effects of this volcano as far north as east and west. Its effect is clearly traced both east and west of the center for a distance of 3 or 4 miles. On the north side of the belt, between the Dexter and the American mines, occur large outcrops of slate, which have an appearance very much like the mingled sedimentary and volcanic material at the east and west ends of the area. These are only about a mile and a half north of the Clarksburg belt, and thus we have here some suggestion of the amount of compression and consequent nearing of these different outcrops which occurred as a consequence of the powerful north-south pressure to which the Marquette series have been subjected.

CHAPTER IV.

THE REPUBLIC TROUGH.

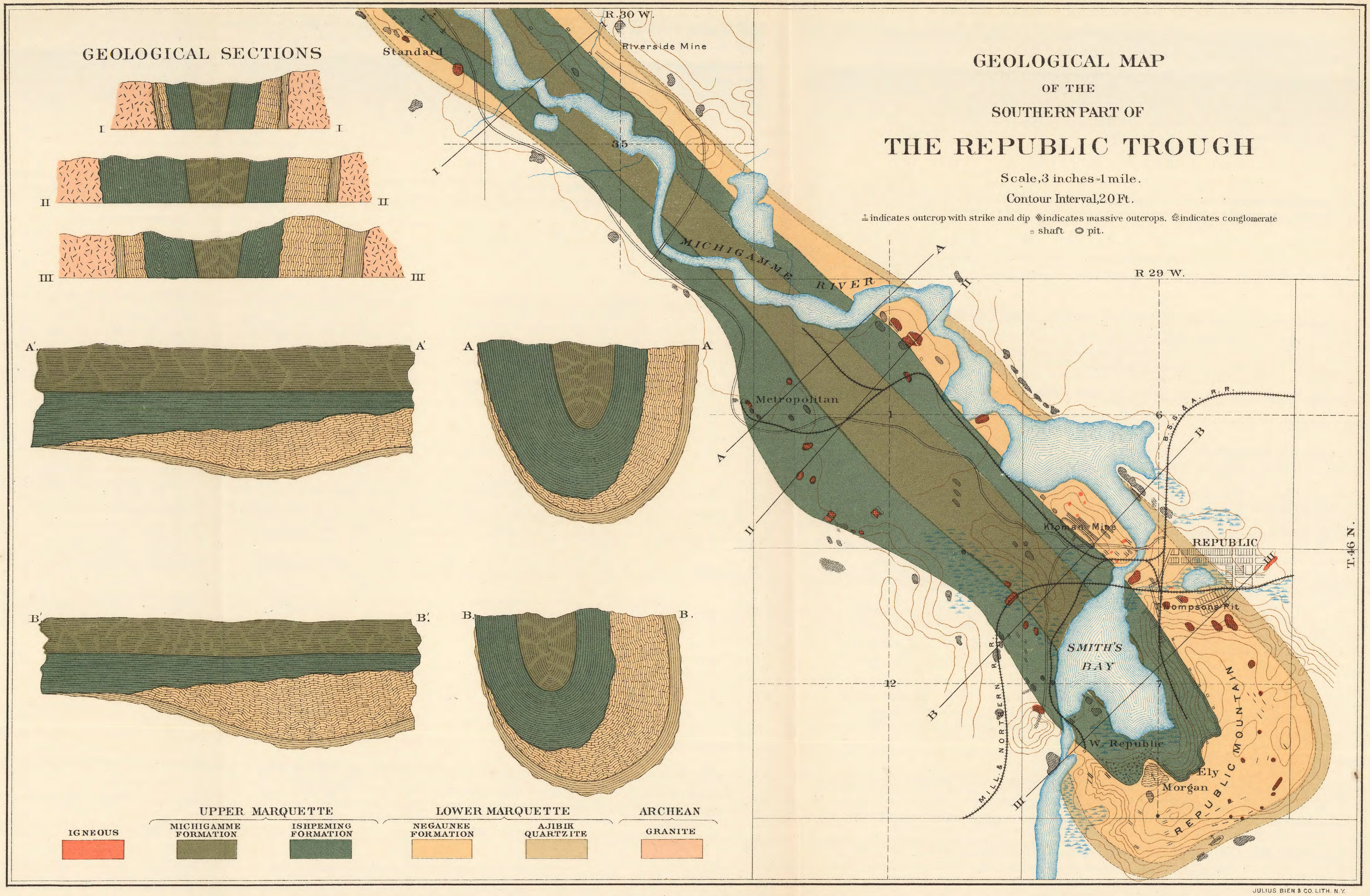
By Henry Lloyd Smyth.

INTRODUCTION.

The Republic syncline (Pl. XXIII) is sharply marked off from the rest of the Marquette district by the simplicity of its structure and by the fact that the folding has taken place about an axis which strikes northwest and southeast, or in a direction considerably inclined to the general course of the great Marquette synclinorium. The Republic syncline is thus transitional to the north and south type of structure that prevails beyond it to the west over three townships, and to the south as far as the Felch Mountain trough in township 42 north. The Republic area proper begins near the south end of Lake Michigamme and continues southeast to the northwest sections of T. 46 N., R. 29 W. As thus defined, it is a simple syncline in Algonkian rocks, about 7 miles in length, with nearly parallel sides from one-half to 1 mile apart; on both sides and at the southeast end it is inclosed by Archean rocks, while at the northwest end it rather suddenly flares out into the main Marquette synclinorium.

To the northeast it is separated from the southern boundary of the main Marquette trough by an area of Archean granite and gneiss about 6½ miles broad. To the west and southwest about half this distance over similar Archean rocks divides it from the next narrow Algonkian syncline. While the general direction of the main Marquette fold is nearly east and west, the fold is constricted on a section through the Champion mine, where it is only 2 miles wide, and its southern boundary has a northwestward trend to which the Republic fold is very nearly parallel.

The topography is as simple as the structure. The Michigamme River, on entering the syncline about 1 mile south of Lake Michigamme, flows through the trough nearly to its southeastern end, mainly over the upper members of the bedded series. The river valley substantially coincides with the bedded rocks. East and west it is flanked by Archean uplands, consisting of rounded granite knobs of characteristic glacial and disintegration forms, often bare or covered with a thin drift mantle.



JULIUS BIEN & CO. LITH. N.Y.

In the immediate neighborhood of the southeastern termination of the trough the river first swings to the east into the eastern granite wall, and then returns to the southwest, occupying a large part of the interior of the trough in the structurally determined expansion of Smiths Bay, and finally leaving it on the western side, about three-quarters of a mile northwest of its southeastern end. Within the general topographic depression bounded by the Archean areas, the bedded rocks and the greenstone intrusives within them occasionally form considerable elevations, none of which, except Republic Mountain itself, reaches the average height of the granite uplands.

The rocks of the Republic area consist (1) of granites, gneisses, and and crystalline schists, which form the basement upon which the iron-bearing series were laid down; (2) of quartzites, mica-schists and ferruginous schists, both of Lower and Upper Marquette age, and (3) of later igneous intrusives.

SECTION I. THE ARCHEAN.

The granites, gneisses, and crystalline schists here constitute the unclassified Archean. These rocks have been studied only incidentally near their contacts with the iron-bearing series, and chiefly from the point of view of their structural relations with the latter. It appears that of the three kinds of rock into which the Archean may be divided, the granites are by far the most common. These are usually normal granular rocks, made up of orthoclase and microcline, plagioclase, quartz, light and dark colored mica, and often hornblende, with the usual accessory minerals. Often the orthoclase is present in large porphyritic Carlsbad twins, which sometimes attain a length of 2 inches. This coarse-grained granite is the prevailing type at Republic. It weathers light-gray or white, sometimes with a marked red tinge. The constituent minerals show no parallel arrangement.

Of gneisses, properly so-called, none have been found in the Republic area except those that have unmistakably been derived from the normal granite by dynamic metamorphism. These are best seen in the immediate neighborhood of the contacts with the overlying series, and they are so characteristic of these contacts that when gneissic foliation is present the contact may confidently be looked for close at hand. This gneissic structure is due to the development of mica, usually muscovite, along surfaces of breaking which, while individually irregular and waving, yet in the aggregate are distinctly parallel in strike and dip with the contact surface and the bedding planes in the overlying sediments.

This structure is most strongly developed at the contact. In departing from the contact it diminishes by degrees, and finally, at distances which usually do not exceed 200 feet, it disappears altogether or is found only in narrow, irregular, and discontinuous zones. That this structure is really due to the processes of dynamic metamorphism acting on the normal granite is evident both from observation in the field, where it may be seen in all stages of development, and also in thin sections, where it is clearly proved to result from granulation of the original quartz and feldspar, and the passing over, in some cases partial and in others complete, of the latter into the new light-colored micas, which are oriented with the directions of fracture.

In the Archean areas are found certain dark-colored hornblende-schists and amphibolites. These occur usually in narrow bands and are exceedingly variable in the degree of schistosity which they exhibit and in crystalline character. Some, at least, are without question old dikes, originally diabase or diorite, in which a parallel arrangement of new minerals has, with more or less completeness, been effected by dynamic metamorphism. In many cases the progress of these changes may be traced from a massive crystalline interior into nearly perfectly foliated zones at the walls. In other cases the schists are completely crystalline throughout, and these bear no evidence of their fragmental character. In age these schists doubtless vary enormously. Some have furnished pebbles to the basal conglomerate of the Lower Marquette series, and these pebbles are as thoroughly crystalline and schistose as any of the schist bands that can now be found in the Archean areas. Others are almost certainly younger than the Upper Marquette sediments, and are genetically connected with the great intrusions of diabases which are found abundantly in this series.

In one locality south of the Magnetic mine a dike of fine-grained red granite was found cutting the ordinary coarse gray granite. No other clear proof of the existence of younger intrusive granites was found in the Republic area proper.

SECTION II. THE LOWER MARQUETTE SERIES.

The bedded rocks of the Republic area belong to two unconformable series of Algonkian age. The lower of these, to which the name Lower Marquette series has been applied, consists of two distinct members, a lower fragmental member of small thickness, probably not exceeding 100 feet, and an upper iron-bearing member, which in its maximum development, including intrusive greenstones, can not be less than 1,500 feet in thickness. The lower member, from its usual lithological character, is generally known as the lower quartzite; while the upper member, from its constant ferruginous character, may be distinguished as the iron-bearing member.

THE AJIBIK QUARTZITE.

The lower member of the Lower Marquette series in this part of the district is relatively a weak rock, and as its thickness is small, it rarely outcrops above the glacial mantle in the Republic area. At the present time but seven or eight localities are known. These are, however, so widely distributed over the area that it is very probable that the lower member is present wherever the Lower Marquette series is repsented at all. In these exposures the rock usually appears as a white quartzite, sometimes vitreous, but often of an opaque white color from the large amounts of contained muscovite or sericite. The mica is frequently present in such abundance that the rock becomes properly a mica-schist. In only one known locality, in which it is found to rest in direct contact upon the Archean, it appears as a coarse conglomerate made up of recognizable fragments derived from the underlying granites and crystalline schists.

In thin section the various phases of this member are seen to be eminently crystalline. The vitreous varieties consist mainly of interlocking areas of quartz, within and between which are plates of light and dark mica and, less often, of chlorite. Magnetite and garnet are more rarely seen, and nearly complete the list of contained minerals. In the more schistose varieties the mica is more abundant, and occurs in long plates which have a parallel physical orientation. In none of the many slides that have been studied do any feldspar grains appear, nor has a trace been detected of the outlines of original rolled grains. These have been obliterated in the course of the profound changes through which the rock has passed since its deposition, and the feldspar of the original granitic débris is now doubtless represented by the light micas and secondary quartz.

In many cases the larger structures of the original rock have survived. Faint color-banding and alternations in texture and composition parallel to the original deposition planes are often seen, and in one locality a beautiful false bedding can be distinctly recognized.

THE NEGAUNEE FORMATION.

The iron-bearing formation is not generally exposed in the Republic area, except at the extreme southeastern end of the syncline, where magnificent outcrops extend from the old Kloman mine in the SW. ¼ of sec. 6, T. 46 N., R. 29 W., almost entirely around the horseshoe, through a large part of sec. 7. Within this area of nearly a square mile, which comprises Republic Mountain, there are small portions only of the interval between the lower quartzite beneath and the upper quartzite above, that are not somewhere represented by outcrops. The rock of the iron formation has many phases, but consists essentially of finely crystalline quartz, a pale-green radiating amphibole which has been determined to be grünerite, and the iron oxides. Within this area the iron-bearing member has been divided by intrusive masses of diorite mainly parallel with the stratification planes, and near the contacts with these it frequently carries large amounts of red garnet. The three chief constituents of this rock are not always present. Two, or even one, may predominate to the partial or nearly entire exclusion of the rest. So the rock is found in certain phases to be made up mainly of quartz and grünerite, or of quartz and iron oxides, or of grünerite and iron oxides. The iron oxides, too, may be either magnetite or hematite. These mineral constituents are arranged in very distinct narrow bands.which are parallel to the upper and lower bounding surfaces of the rock. The bands are not wholly regular, nor are they continuous for great distances. They thicken and thin, taper out and break joint. It is certain that none of the minerals which now make up the rock are original, and that the parallel banded structure signifies that the processes of metamorphism through which it has reached its present constitution were controlled by a primary bedded structure.

The variations in external appearance produced by these considerable variations in composition are great. These variations are not wholly irregular, and it is possible to distinguish in the different phases a definite distribution through the iron-bearing member, which holds good within the limits of the Republic area. The lower portion of the formation is, on the whole, characterized by the presence of grünerite and gray or dark-colored quartz with magnetite, while the higher portion is characterized by the almost complete absence of grünerite and by the presence of specular hematite and red quartz or jasper, which owes its color to the intimate mixture of the little particles of hematite with the quartz. The study of the western portion of the Marquette area alone would probably justify, on the basis of difference in composition and external appearance, a division of the iron-bearing member into two distinct formations, a lower grünerite-magnetite-schist member and an upper specular jasper member.

In the Republic area magnetite also increases in amount in going from lower to higher horizons, while grünerite decreases, so that just beneath the specular jasper the iron-bearing member is mainly made up of bands of exceedingly fine-grained magnetite alternating with bands of dark to black quartz, the color of which is due to the presence of a large amount of included magnetite.

Under the microscope the chief interest centers in the question of the nature of the quartz, whether it is partly or wholly of fragmental origin.

In the study of the slides, which is not yet completed, no evidence has yet been found that any of the quartz is fragmental. Here and there traces are seen of an original oölitic structure, such as is so beautifully shown in the more modern and less altered iron formation of the Mesabi Range. In the Michigamme jasper of the Menominee district, which is regarded, on stratigraphical grounds, as the equivalent of the Lower Marquette iron formation, an original oölitic and concretionary structure is common.

The question of the nature of the rock from which the iron-bearing member has been derived is fully discussed by Professor Van Hise elsewhere in this memoir. Whether, as seems probable, the various phases which the iron-bearing member now presents have been derived from a single original rock of sensibly uniform character or not, it is very evident that much of the differentiation is of long standing and occurred before the Upper Marquette transgression. That this is so appears from the presence of pebbles from both the magnetite-grünerite-schists and the specular jaspers in the basal conglomerate of the Upper Marquette series. In the Republic and adjacent areas at least, the specular jaspers occur at a definite stratigraphical position in the highest horizon in the Lower Marquette series. They are present only in those places where large thicknesses of the lower series remain, as at Republic Mountain and in the range along the northwest side of Lake Michigamme. Where the lower series has been more deeply eroded before the deposition of the Upper Marquette rocks the specular jaspers are far less continuous and of less common occurrence than the magnetite-grünerite-schist phases of the iron-bearing member. These facts appear to bear strongly against the view that the specular jaspers are due to later metamorphic processes which acted along the contact with the Upper Marquette quartzite after the latest folding, while they are what would be expected if these two chief phases existed in substantially their present condition before the Upper Marquette series was laid down.

Another fact is also significant. It has been said that the present grünerite, quartz, and iron oxides of the iron-bearing member have a very distinct banded arrangement and yet are not original minerals, and that this banding is parallel to the upper and lower boundaries of the formation. It is probable that a set of parallel structural planes has controlled the segregation of the present constituent minerals in the changes through which the rock has passed, and that these planes must have been original bedding planes. As the parallel banding is confined to this one direction, it is certain that during its development no other system of parallel planes existed in the rock. The last severe folding which has determined the larger structural features of the Marquette district has also affected the rocks in a more intimate way. In certain localities strong minor, even minute, crenulations have been produced, and also parallel cleavage which sometimes traverses the banding of the rock at right angles. The little folds are often broken and faulted and the siliceous bands reduced to fragments. Along the parallel cleavage planes movement has often taken place, as is shown by the displacement of a particular band on the two sides. Along this secondary cleavage, which dates from the period of general folding after Upper Marquette time, no great development of new minerals, except the iron oxides, has taken place, while the displacement which the minute faulting has caused in the banding conclusively proves that this structure was present before the folding.

From these various lines of evidence, from the apparently definite stratigraphical position of the two main varieties of the iron-bearing member, from the presence in the upper conglomerate of pebbles of all the various kinds of rock which are now found in the iron-bearing member, and from the mechanical effects which the last folding has produced in the banded structure, it seems beyond question that the iron-bearing formation had essentially its present character at the time when the Upper Marquette series was laid down.

CONTACTS BETWEEN THE LOWER MARQUETTE SERIES AND THE ARCHEAN.

It has already been said that the Ajibik quartzite has been found in only a few places. The contact between this rock and the Archean is almost everywhere drift-covered, and actual juxtaposition has been found in but two localities. The evidence at one of these as to the relations between the two series is very clear and convincing.

In the eastern part of the NW. ¼ of the NE. ¼ of sec. 18, T. 46 N., R. 29 W., is a large outcrop of the quartzite, which was discovered by Pumpelly and Credner in 1867. The locality is at the extreme southern end of the Republic syncline. A short distance southwest of the quartzite is a ridge running northeast, made up mainly of granite. Near the southwest end and on the northwest side of this ridge, which has a steep northwest slope, is found, lying upon the granite, a northwesterly dipping fringe of conglomerate which extends some 50 feet along the strike as a continuous rock mass and occurs besides in occasional disconnected patches farther north on the sloping face of the hill. The granite is of the usual gray variety, and carries large orthoclase crystals up to 2 inches in length.

The conglomerate consists of pebbles of granite, quartz, and black hornblende-schist embedded in a matrix of quartz and mica-schist. The cement is distinctly color-banded, the bands being parallel to the contact surface. They are thrown into small folds about axes which pitch northwesterly in the direction of the dip of the rock. The pitch is closely parallel both with the axis of the main Republic fold and with a pronounced parallel cleavage which affects the overlying grunerite-magnetite-schists, the conglomerate cement, and also the underlying granite for a considerable distance back from the contact. The granite pebbles vary in size from a fraction of an inch up to 5 feet in diameter, and are all unmistakably water rounded. The larger are comparatively thin slabs, lying with their flat sides in the bedding of the matrix which often follows round the inclusions. The granite of the pebbles is lithologically identical with that of the main mass on which the conglomerate rests.

The contact itself is very definite. Between the undoubted conglomerate above and the undoubted granite below is a narrow zone, a few inches wide, of schistose material, which probably represents a shear zone affecting both rocks, due to movement along the contact during the folding. At the north end of the main outcrop a large mass of granite is traversed by thin seams of the conglomerate, one of which tapers to a point at one end and connects with the main body of conglomerate at the other. It is impossible to avoid the conclusion that this represents an original crack in the somewhat irregular surface upon which the conglomerate was laid down, into which the finer sand and pebbles were washed.

The facts at this contact can only be interpreted as signifying that the gray granite upon which the conglomerate now rests existed in its present condition at the time that the conglomerate was laid down, that it supplied a large part of the materials out of which the conglomerate was built, and furnished the basement upon which it was deposited. In short, the contact is one of erosion, the conglomerate is a basal conglomerate, and the facts indicate an important time-break at its base.

At the other locality in sec. 7, T. 47 N., R. 30 W., a short distance south of the Magnetic mine, the evidence is not so clear. Between the undoubted granite and the iron-bearing member is a considerable interval occupied by banded gneisses and mica-schists, which certainly include part of the horizon of the lower quartzite, but how much it is impossible to determine. Some of the gneisses and schists have evidently been derived in place from the granite, through shearing parallel to the contact; others seem clearly to be metamorphosed sediments in which it is possible to detect here and there traces of the larger quartz pebbles. But between them there is a considerable interval of somewhat similar gneisses and schists, of which the origin is wholly indeterminate. The facts here are quite in harmony with the view that the contact is an erosion contact, although they do not give it direct support.

The two contacts therefore, at which direct juxtaposition is found, justify the conclusion that the relations between the Lower Marquette series and the Archean are those of an erosion unconformity, that the Archean in its present form is the older, and that a considerable interval of time elapsed between the formation of the Archean rocks and the deposition of the Ajibik quartzite.

The lithological character of the Ajibik quartzite, wherever it is found, must be taken as corroborating this conclusion. It will be remembered that this rock is composed of quartz with variable proportions of light-colored mica, muscovite, or sericite as essential constituents. These micas have probably been derived from the alteration of original orthoclase or microcline, feldspars characteristic of the Archean granites, of which the quartzite otherwise shows now no traces. The quartzite was then probably a feldspathic sandstone, composed of granitic débris such as the breaking down of the adjacent underlying granite would unquestionably furnish. The persistence of its lithological character, and the fact that it is always found now in close proximity to granite, the disintegration of which would have supplied all of its essential constituent minerals, certainly raise a strong presumption that such actually has been its origin.

SECTION III. THE UPPER MARQUETTE SERIES.

In the Republic area proper only the lower member of the Upper Marquette series, the Goodrich quartzite, is well exposed. This is in the main a white quartzite, usually massive and heavily bedded near the base, and passing upward into the mica-schist of the Michigamme formation. At the base, conglomerate layers occur, in the pebbles of which all the underlying rocks are abundantly found. The conglomerates, while usually unimportant, are represented in great volume at the south end of the trough, where they are beautifully exposed by the extensive mining operations about Republic Mountain. In these conglomerates the great majority of the pebbles have a local origin, being derived from the rocks upon which the conglomerates directly rest.

Under the microscope the Goodrich quartzites and quartz-schists show a decidedly less degree of metamorphism than do the Ajibik quartzites. Roundish grains of feldspar, usually microcline, derived from the underlying granites, are plentiful, and the quartz areas often exhibit distinct indications of original rolled nuclei. In the quartz-schist and mica-schist, into which the more massive quartzite usually passes upward, certain definite layers of a darker color are often distinguishable, in which iron oxides, usually magnetite, abundantly occur. In these layers false bedding is often strongly brought out, and it is believed that the iron oxides are in large part original sediments.

The Goodrich quartzite is, on the whole, the thickest rock in the Republic area, and, by reason of its volume and character, that which most frequently outcrops.

The Michigamme schist occupies the center of the tongue and because less resistant than the inferior formations, the Michigamme River does not wander far from its borders. In most respects this schist is similar to the remainder of the formation elsewhere, and therefore will not be further considered here.

CONTACTS OF THE GOODRICH QUARTZITE WITH THE LOWER MARQUETTE SERIES AND WITH THE ARCHEAN.

Direct contacts of the quartzite which forms the base of the Upper Marquette series with the underlying rocks are very numerous, and the evidence in detail, as well as the more general facts, leaves no room for doubt that this quartzite was laid down on a deeply eroded surface and that the relations are those denoting a most profound time break.

The detailed facts which may be observed on the exceptionally fine exposures about Republic Mountain are these: (1) There is a slight but very persistent discordance in stratification—more evident, at any single locality, in dip than in strike—between the upper quartzite and the underlying formation of the lower series. This difference in dip is on the average not far from 15°. (2) The basal conglomerate of the upper series is crowded with fragments of the iron-bearing member upon which it lies. These fragments are often of large size and imperfectly rounded, and evidently have not moved far. The included fragments at the immediate contact are almost wholly from the subjacent formation, and from their often irregular shapes and great preponderance might frequently be mistaken for the products of brecciation, if it were not for the sparse presence in the conglomerate cement of quartz and feldspar derived from the more distant granites. (3) The structural details of the contacts prove unconformity. The layers of the underlying iron formation are often for short distances traversed at large angles by the contact surface. Extending back into the mass of the iron formation cracks are occasionally found, into which the fine material of the conglomerate cement has sifted. Finally, in the conglomerates in the lower member of the upper series pebbles of all the underlying rocks are seen, from the Archean to the top of the Lower Marquette series.

The more general facts of the relations of the Upper Marquette series to the underlying rocks may be summed up in the statement that within the narrow limits of the Republic area the upper series rest, in one locality or another, on each of the older formations. (Pl. XXV.) The maximum thickness of the Lower Marquette series is found at Republic Mountain. In going north from Republic Mountain on the east side of the fold the lower series is progressively and rather slowly cut out, so that at the old Chippewa exploration in sec. 22, T. 47 N., R. 30 W., the Goodrich quartzite rests directly upon the Archean. Thence northward, round almost to the Champion mine, the lower series probably does not again emerge.

On the west side of the fold the lower series is entirely gone on the west side of the river, opposite the Republic mine, and the Ishpeming quartzite rests directly on the granite. It reappears to the north only in patches, once at the Standard location, possibly again at the Metropolitan, and again at the Erie. Beyond the Erie it appears again and continues beyond the Magnetic mine and the limits of the area now described.

The evidence, which it is not thought necessary to present here in greater detail, is thus conclusive, and settles beyond the possibility of question the fact that between the deposition of the Lower Marquette series and that of the Upper Marquette series an interval of time elapsed, during which the lower series was elevated, folded, probably metamorphosed, and deeply denuded. This break in continuity of deposition between the two series lasted sufficiently long to permit the removal in many places of the entire Lower Marquette series, and a deep gnawing into the Archean. The present uneroded thickness of the Lower Marquette series on Republic Mountain is at least 1,500 feet. How much in all was removed by erosion before Upper Marquette time there is no means of knowing. Fifteen hundred feet of Lower Marquette strata, with an unknown thickness of Archean, is the minimum amount taken away in the Republic area. The time-break in the Marquette district is far less impressive than that below the upper series on the north shore of Lake Superior (with which, indeed, we do not know that it was conterminous), because the earlier folding on the south shore was less severe, while the later folding, which followed Upper Marquette time, was far more severe than on the north shore; and hence the structural discordances and the differences in degree of metamorphism between the two series are less pronounced. But the conviction remains that this is one of the great breaks in the geological record.

SECTION IV. LATER IGNEOUS INTRUSIVES.

These are the diorites of Brooks, and they occur in great abundance both in the upper and lower series. They are dark green to black, often coarsely crystalline rocks, composed essentially of green hornblende, biotite, and plagioclase, and doubtless were originally diabases. They occur in sheets intruded parallel to the stratification of the bedded rocks, in dikes, and in irregular bosses. The great regularity of some of the intruded sheets, such as those on Republic Mountain, is remarkable, and led Brooks to regard them as regularly interbedded and continuous members of the stratified series. Close examination, however, shows that even here they often really traverse the banding of the iron-bearing member at small angles or in steps. In one case a dike several feet wide was found to leave the main sheet and to cut the structural planes of the inclosing jasper at an angle of 45°. In the immediate neighborhood of the ore deposits bodies of so-called soaprock are found, which have in many cases intrusive relations to the iron-bearing member. At Republic it was not possible to follow these soaprock bodies in any instance into a rock which retains traces of an original crystalline structure, but at the Champion mine exactly similar soaprock, occurring in similar relations to the ore, in several instances was found to run into typical diorite.

In age, many, probably most, of these rocks are younger than the Upper Marquette sediments. Some, however, penetrated the Lower Marquette series before Upper Marquette time. In sec. 23, T. 47 N., R. 31 W., the basal conglomerate of the Upper Marquette series is seen to rest upon and to hold numerous fragments of an old diorite. Within the Republic area no surface eruptives have been seen in either the upper or the lower series.

SECTION V. GENERAL GEOLOGY.

All the rocks of the Upper Marquette and Lower Marquette series have been closely folded in the Republic area into a syncline, the axis of which runs about northwest and southeast. The present fold for most of its length is sunk deeply into the Archean, and the axis is practically horizontal. Southeast of Smiths Bay, however, the axis rises with a pitch of nearly 45°, the several formations swing round successively in horseshoe form through an agle of 180° from the northeastern to the southwestern side, and the fold, so far as it affects the Algonkian rocks, abruptly terminates. Through the greater part of the length of the trough the rocks on the two sides of the axial plane have been squeezed nearly into parallelism. None of the many surface observations show in the Ishpeming quartzite a dip less than 80°. The formations in the underlying Lower Marquette series dip at a uniformly higher angle on the eastern side, and are either vertical or slightly overturned toward the west, while on the western side, owing to the general absence of the lower series, observations are rare, but a similar divergence in dip is found in two or three places.

If the base of the Goodrich quartzite is developed into a horizontal straight line along any cross-section (thus approximately restoring the conditions to what they were before the last folding), it will be seen that the rocks of the underlying lower series on the two sides of the trough dip toward each other. (Pl. XXV, Secs. A A and B B.) This convergence in dip along a developed section points clearly to the existence of a gentle syncline in the Lower Marquette series before Upper Marquette time, within the limits of the present fold. The very slight discordance between the strikes of the members of the two series which, broadly regarded, is measurable in feet per mile, rather than in degrees, would indicate that the axis of the later fold is sensibly parallel to that of the older, while the greater thickness of the lower series remaining on the east side of the present trough than on the west, gives good ground for the inference that the axis of the old syncline lay somewhat east of the present axis. This previously existing synclinal axis doubtless determined in the later folding the position of the present trough.

It has been said that the trough as a whole pitches to the northwest at its southeast end at an angle of about 45°. This is not far from the average pitch at the surface. With depth this angle slowly diminishes, and at about 900 feet below the surface it is less than 40°. The distance in which the turn is made at the southeast end of the trough is relatively very short. The average radius of the generalized curve into which the base of the Goodrich quartzite has been thrown can be very little greater than the thickness of that formation. (Pl. XXV, Secs. A A and B B.) Field study shows clearly that the neutral surface of the column of folded material lay below the base of the upper quartzite, and included a considerable portion of the grünerite. This is proved by the severely plicated condition of the thin-bedded jaspers, and by the same structure on a larger scale in the more heavily bedded quartzite. The crowding of the rocks above the neutral surface into a very constricted space resulted in the formation of three larger synclines separated by two anticlines, all subordinate to the main fold. The most eastern of the synclines occurs at the great open pit of the Republic mine; the middle, in the ground opened by the Morgan, Pascoe, and Ely shafts, and the westernmost at the Swamp shaft. These larger subordinate folds are accompanied by a multitude of smaller anticlines and synclines of various dimensions. They are more numerous and more closely compressed in the iron-bearing member than in the Goodrich quartzite.

In the iron-bearing member, which is a thinly bedded rock, these little folds are especially numerous in the Morgan-Pasco-Ely syncline and in the anticline immediately west of it. The effect of this prevalent crinkling and close compression is to give a general northwesterly direction to the individual bands, which, in the narrow spaces open to observation underground or in small outcrops on the surface, may lead to erroneous conclusions as to the real direction of the strike and dip of the rock. This northwesterly structure is really at right angles to the direction of continuity of the rock. The true strike is determined by the plane tangent to the little folds, and the true dip by the angle of pitch of their axes. Even on the surface in the larger outcrops the observer may sometimes be misled. The larger subordinate anticline between the Swamp shaft and the Morgan is topographically indicated by a high spur, on which the specular jasper outcrops. The jasper is thrown into innumerable little folds, the axes of which pitch to the northwest at an angle of less than 45°. The northern slope of the spur is nearly as steep as the angle of pitch, and so the surface cuts the little folds nearly parallel to their axes. In effect, therefore, the jasper outcrops on this northern slope show a parallel banding striking northwest. On the top of the hill, however, the true strike is clearly brought out on the vertical cross joints.

The Goodrich quartzite, which is a much more massive and heavily bedded rock, yielded to the intense compression by differential movements of one bed on another, and doubtless also by thickening. The effects of the movement of bed on bed are clearly and strikingly shown at numerous points in the horseshoe, perhaps particularly well in the small open pit east of the Ely shaft. Here the individual quartzite beds, from 1 foot upward in thickness, are separated by parallel selvages of ground-up quartzitic material, varying in thickness usually from 2 to 4 inches. In the case of one the measured thickness was 11 inches. These selvages, known locally as a variety of "soaprock," show frequently a vertical pressure cleavage.

FAULTS.

Maj. T. B. Brooks shows, on his large scale map of Republic Mountain[1] and vicinity, the course of a probable fault cutting diagonally across the syncline in a northeasterly direction along the river in sec. 7, north of the horseshoe. Brooks was led to infer the existence of this fault from the fact that he regarded the diorites as regularly interbedded and continuous members of the stratified series, and from his failure to recognize the break in continuity of deposition at the base of the Goodrich quartzite.

[1] Geol. Sur. of Mich.: Atlas accompanying reports on Upper Peninsula, Pl. VI by T. B. Brooks. 1869-1873.

On the northeast side of the syncline diorite outcrops a short distance north of the Milwaukee and Northern Railroad water tank, on the east side of the river, and lies directly in the line of strike of jaspers that are well exposed a few hundred feet away on the west bank.

On the southwest side of the syncline, north of the horseshoe, the Lower Marquette rocks which lie below the Goodrich quartzite on the east side of the river, would, if prolonged along the strike, be carried directly into granites which occupy the west bank, west of the West Republic mine. Hence, on Brooks's assumptions, there is displacement on both sides of the trough at the line of the river, and a fault is clearly indicated.

It is susceptible of demonstration, however, that no fault exists involving the Goodrich quartzite. On the northeast side of the fold the contact of the upper quartzite on the lower series, which is a surface of economic interest, has, since the time of Major Brooks's studies, been definitely fixed at numerous points where it is not naturally exposed by diamond-drill borings on both sides of the river. These points when accurately platted, fall on a line which shows no displacement at the river.

At the southwest side of the fold the upper quartzite is abundantly exposed on both sides of the river, and its base has been located at many points in the West Republic mine, under the river, and in several test pits and drill holes on the western side. The platting of these data shows conclusively that no displacement can exist which has thrown the upper quartzite to the extent of 100 feet.

The disappearance of the lower series on the west side of the river, on the southwestern side of the fold, presents, however, a real difficulty. That its absence is due to a sudden bending of the strike toward the northeast is very improbable, because in the few outcrops of the iron-bearing member nearest the river there is almost perfect conformity in strike with the upper quartzite. Also, underground in the West Republic mine, the jasper was followed nearly to the west bank of the river. It seems necessary to believe, therefore, that the formations of the lower series continue without sensible change in strike as far as the river, and there terminate squarely against the granite. Such relations can be explained only by supposing that the granite on the west bank either had intruded the lower series, or had been brought to the level of the old surface by a fault before Upper Marquette time. Between these two explanations there is no present means of choosing.

On Brooks's map, already referred to, a tongue of the upper quartzite is represented as forking from the main mass of the same rock and running northwest along the top of the Republic bluff, a thin wedge of the underlying specular jasper being interposed between them. No explanation of this singular fact was given by Brooks in the text of the Michigan report.[1] Dr. Wadsworth has lately endeavored to explain

[1] Report of the State Board of Geological Survey, Lansing, 1893, pp. 129–130.

these relations by the assumption that the wedge of the specular jasper included between the two quartzites does not belong to the lower series but to the upper, and was deposited later than the quartzite tongue. It is believed, however, that the phenomena are really due to faulting. (Pl. XXVI, fig. 2.)

The best exposures of the two quartzites, the included jasper, and the underlying iron formation of the lower series, with all the contacts, may be seen on the natural cross-section afforded by the breaking down of Republic Mountain north of the Thompson pit. The conglomerate at the base of the main mass of the quarztite is exposed on the steep western face of the bluff. It holds pebbles of red jasper, of jasper banded with ore, of ore, and of quartz, which last with ferruginous matter forms the cement. The jasper inclusions are large, many of them are angular, and near the contact small quartz grains fill irregular cracks in the underlying jasper tongue. The conglomerate is distinctly basal, and unquestionably was laid down on an eroded surface. From this contact, for about 16 feet in the east, the jasper tongue comes in. This rock is greatly brecciated, but it contains no mixture of foreign fragmental material. To the eye and under the microscope it is not to be distinguished from the ordinary specular jasper of the underlying iron formation. For the next 5 feet occurs a mixture of large angular pieces of jasper (one measured 3 by 1 feet), of quartz, and probably quartzite, many somewhat rounded pebble-like forms of all these, and much siliceous cement. About 6 feet of westerly dipping quartzite, constituting the quartzite tongue, follow and then come 3 to 4 feet of conglomerate, entirely similar to the first conglomerate and having similar relations to the specular jasper, which continues in an unbroken body to the east.

The significant facts at this contact, which seem clearly fatal to the idea that the jasper is an interbedded member of the upper series, are these: The conglomerate at the base of the main quartzite is as clearly separated from the jasper wedge by an erosion interval as the conglomerate below the quartzite tongue is from the main mass of specular jasper. The jasper wedge can not belong to the upper series unless there are two upper series. The jasper of the wedge, also, is not a fragmental rock, and in it no contemporaneous fragmental material has been recognized except near the lower and upper contacts. It disappears a short distance south of this section, the two quartzites coming together. If this is a member of the upper series, it must have been laid down at the same time that a rather coarse fragmental rock was being deposited a few hundred yards away. It is hardly conceivable that under these circumstances clastic material should not have mingled with it.

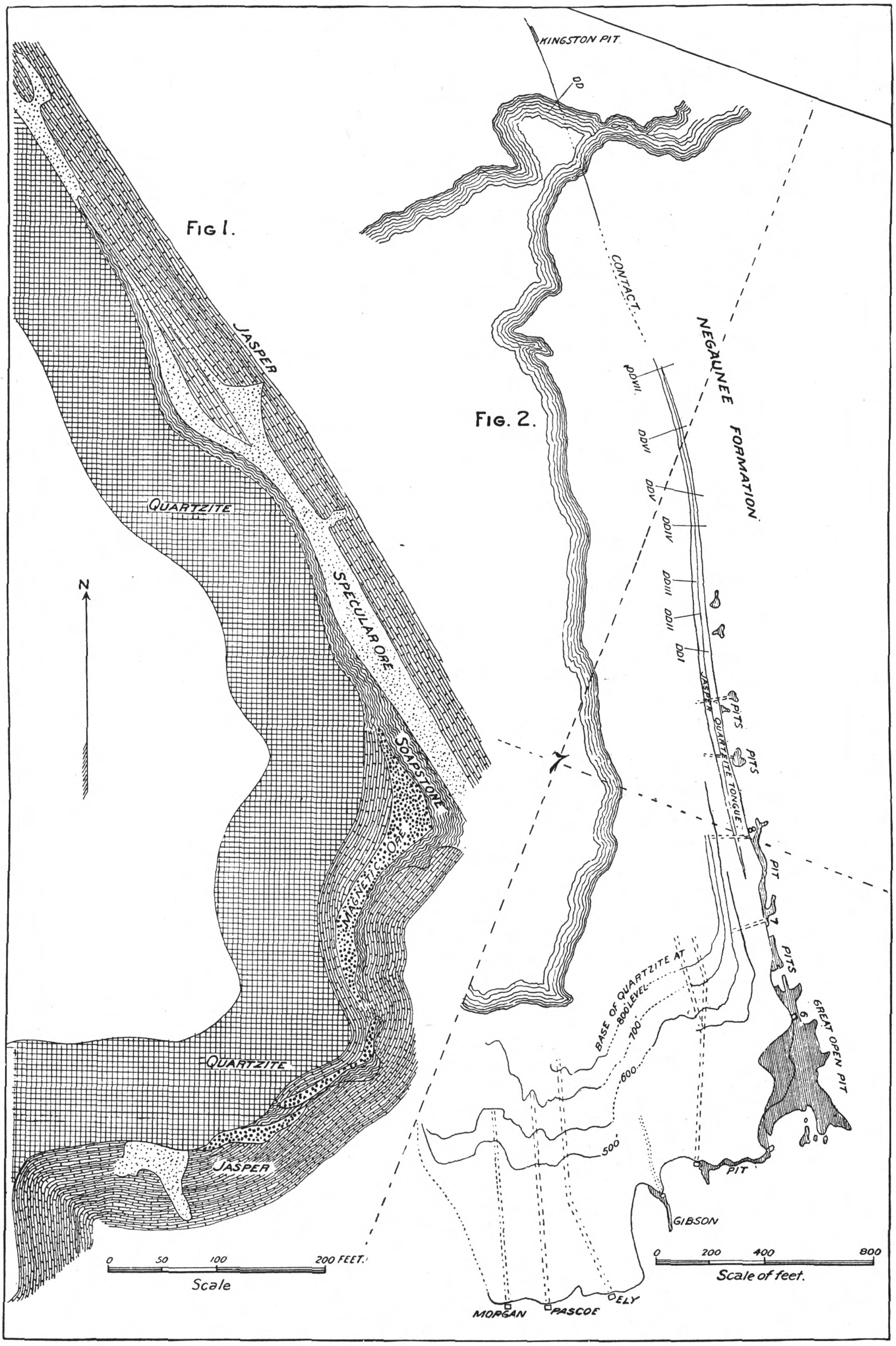
While the relations of the quartzite tongue are correctly represented on Brooks's map, the vastly better surface exposures of the present day and the large amount of exploration done by the Republic company enable its position now to be fixed with much greater precision.

PLATE XXVI.

PLATE XXVI. GEOLOGICAL MAP OF SOUTHEAST END OF REPUBLIC HORSESHOE.

Fig. 1. Southeast corner of the horseshoe, showing the surface relations of the magnetite and hematite to the jasper, quartzite, and soaprock. The larger ore deposits of magnetite are bottomed by soaprock, making steeply pitching troughs. The specular ore is for the greater part of the distance separated by a belt of soaprock from the magnetite ore and quartzite.

Fig. 2. Map of the vicinity of Republic mine, showing the contact between the Lower Marquette and Upper Marquette series and the quartzite tongue. It will be seen that the great ore deposits occur in the two plunging synclines at the southeastern and southern end of the trough.



GEOLOGICAL MAP OF THE SOUTHEAST END OF THE REPUBLIC HORSESHOE.

Several diamond-drill holes north of the Thompson pit have shown that it extends 500 to 600 feet north of the point where it terminates on Brooks's map, and becomes steadily narrower. As it does not appear at the Kingston and Kloman exposures, on the west side of the river, there is little doubt that it gradually dies out, and that the jasper wedge finally merges into the main body of specular jasper.

Therefore the facts to be explained appear to be these (Pl. XXVI, fig. 2): A quartzite tongue branches in the south from a large mass of similar quartzite, and after continuing parallel to it for a long distance finally tapers to a point in the north in a mass of specular jasper. The quartzite tongue includes between itself and the main quartzite mass an exactly similar jasper tongue, which starts in the north from a mass of specular jasper and tapers to a point in the south in quartzite, the two tongues interlocking. The quartzite in each case, in the tongue and in the main mass, has similar and unusual relations (those marking a time break) with the jasper of the tongue and of the main mass. The identity of the two jaspers and of the two quartzites must be taken as established, and the explanation of the facts must be sought in faulting.

In the horseshoe turn the material above the neutral surface yielded to the compression in part by slipping along bedding planes. If for any reason such movement could take place more readily along any one surface, the neighboring surfaces would be relieved and one of maximum movement would result. It is conceivable that in the same way one local maximum might relieve several neighboring maxima, and so a large amount of movement might be accumulated along a single surface. A maximum movement starting in the specular jasper would, on account of the slight upward convergence of dip, necessarily tend to cut across the quartzite at the contact. The quartzite might be traversed until a surface of maximum movement in it was reached, which would then be followed and a fault would result, which in the direction of the strike might easily pass from one rock to the other more than once. It is evident that a break formed under such conditions, accompanied by considerable displacement, would result in the surface relations that may now be observed on Republic Mountain.

THE ORE DEPOSITS.

Position of ore deposits.—The iron ores of the Republic area all belong to the hard-ore class, and are both magnetite and specular hematite, the specular slate ores being the more abundant. They occur in bodies of very irregular shape and sometimes of great size. The rule that has generally guided exploration in the Marquette district, that the hard-ore bodies occur immediately at or not far beneath the base of the upper quartzite, holds good in the Republic area. It is a significant fact that while this rule of occurrence beneath the upper quartzite has few or no exceptions, the position of the ore bodies with reference to the base of the lower series is exceedingly variable. At Republic Mountain and at the Michigamme mine the ore bodies lie at least 1,500 feet above the granites. At Champion and at the Riverside mine the distance is not more than 400 feet. The hard-ore bodies are therefore not confined to any one horizon in the iron-bearing member, but occur at the particular horizon to which it happened to be eroded at the time the upper quartzite was deposited. The relationships of the contact deposits of the Republic area are with both the lower and upper series. Some are apparently entirely within the upper series; others are certainly entirely within the lower series; others again are partly in both. The form of the bodies is exceedingly irregular, but in general terms they may be described as pod-like in shape, the two horizontal dimensions being usually very much smaller than the third, which follows down roughly parallel to the dip plane of the quartzite, often pitching to one side of the normal vertical plane. Of the two horizontal dimensions, the longer is usually parallel with the stratification, and the shorter normal to it.

When the ore deposits are wholly contained within the lower series, the contacts between them and the rock of the inclosing iron formation are usually as follows: The siliceous bands in the ferruginous rock become separated into lenses by the encroachment of the adjoining iron bands at frequent intervals along their length, and grow narrower. The siliceous material of which they are composed becomes mixed with a larger proportion of the iron oxides, and as the boundaries of the rich ore are approached the bands separate into oval-shaped units. These finally disappear partly or entirely, and the adjacent iron oxides fill the whole volume of the banded rock. Such passages from the banded rock of the iron formation to rich ore take place both along and across the strike. Sometimes the passage is very gradual, leaving a large zone of more or less lean ore between the rich ore and the rock; but often it is very sudden, and the line of demarcation is sharp. Such sudden passages have been observed at the line of cross joints, along which minute faultings have taken place. It is unusual to find any ore deposit, however, that is directly surrounded by the iron formation rock on all sides. Generally on either the hanging or foot wall soaprock intervenes between, somewhere along the surface of contact; and in these cases the iron formation is usually present unaltered on one side, while the rich ore comes up to the soaprock on the other. These bodies of soaprock have already been referred to as old dikes and intrusive sheets of igneous material.

Of the deposits entirely within the upper series two classes may be distinguished. The first are those deposits which lie at the base of the upper series, and really represent an enriched, very ferruginous phase of the basal conglomerate. At many localities the Upper Marquette conglomerate is made up of siliceous pebbles embedded in a cement of iron ore, part of which is in many cases unquestionably detrital. When the quartzose pebbles, from the condition of sedimentation, happen to be few and small, or when they have been removed by subsequent changes, the conglomerate may contain enough iron to constitute a valuable ore. No large deposits of this character have been demonstrated to exist in the Republic area, but some good examples on a small scale may be seen about Republic Mountain. It is believed that a considerable part of the magnetite deposits of the Champion mine belong to this class. Such ores are usually magnetic in the Republic area also, and round the borders of the rich deposits, when they become too lean to mine, occur certain peculiar rocks, mixtures of clear quartz and magnetite, which are usually known as "black-ore jasper." Higher up in the lower quartzite thin, regularly bedded bands of magnetite and quartz occur, which occasionally rise high enough in iron to become ores. They are found usually a short distance above the transgression plane, and are separated from it by a small thickness of quartzite.

In certain cases the line of contact between the upper and lower series may be traced directly through an ore body, which thus belongs partly in one series and partly in the other. Excellent examples may be seen at the Kloman open pits, north of Republic Mountain.

Relations between the ore deposits and the geological structure (Pl. XXVI, fig. 1).—In the Republic area the only deposits that have had a commercial value have been found in the immediate vicinity of the southeast end of the fold. The largest single body occurs at the northeast end of the horseshoe, in the easternmost of the three main subordinate synclines, already mentioned. The middle, or Morgan-Pascoe-Ely syncline, is the locus of a great number of smaller deposits. Several deposits occur also on the straight eastern side of the trough, within three-quarters of a mile from the horseshoe; but in going north along this stretch the bodies become smaller and farther apart, and north of the Kloman practically disappear. A very close relation is thus indicated between the occurrence of the iron ore in large deposits and the main structural features of the trough.

These larger bodies are both magnetite and specular hematite or slate ore. (Pl. XXVI, fig. 1.) The magnetite bodies always occur immediately below the upper quartzite, with which they are frequently directly in contact. More commonly, however, the rich ore is separated from the quartzite by a small thickness of black-ore jasper or mixed magnetite and quartz, usually banded, or sometimes by soaprock; while immediately beneath and continuous with the rich magnetic ore, specular ore is sometimes found. Soaprock usually, and in the case of all the larger bodies invariably, forms the foot wall. The magnetite deposits are mostly confined to the eastern and middle subordinate synclines, but are also found of small thickness in depth along the straight eastern limb of the main fold.

The specular hematite or slate-ore bodies occur both in the contact zone and below it entirely within the specular jasper. (Pl. XXVI, fig. 1.) The deposits of the contact zone as a rule contain the richest ore, which is characterized by the large size of the individual crystalline plates. As a deposit is followed back from the contact zone into the jasper, these plates become progressively smaller, and at the same time the ore grows more siliceous. The specular ores are frequently associated with soaprock, which may bound the deposit either on the foot or hanging wall side; but it is perhaps as often absent as present.

The deposits of specular ore that occur along the straight eastern limb of the fold all show a well-marked pitch toward the north, in the general direction of pitch of the main fold, but at a very much higher angle. These bodies all lie in the contact zone at the surface, having the upper quartzite on the hanging wall. As they are followed in depth they are found to recede from the quartzite, and to follow the banding of the underlying jaspers, which dip at a higher angle than the quartzite. They terminate in depth entirely within the specular jasper. As one body departs from the quartzite and becomes entirely inclosed by the jasper another frequently comes in above it in the contact zone.

The deposits in the subordinate synclines in the horseshoe turn have not shared the intense crumpling to which the specular jaspers have been subjected. They occur in thin, unwarped sheets, which start with one edge in the contact zone, having the upper quartzite on the hanging wall, and set back from it parallel with the local strike of the closely folded jaspers. The longest dimension thus follows down the contact, pitching with the dip of the quartzite, while the longer of the two horizontal dimensions is usually normal to the strike of the quartzite. These deposits occur in the arches or on the limbs of the minor contortions, and never, so far as observed, occupy the troughs. Their attitude with reference to the general strike of the quartzite, and the fact that they do not show the contortions of the inclosing specular jasper, prove that they have come into existence since the folding.

Origin of the ore deposits.—From the form and general relations of the rich ore deposits, it is evident that they were not laid down as bodies of rich ore contemporaneous with the inclosing rocks. It is not conceivable that nearly pure silica and nearly pure iron oxides could be deposited under water at the same time on opposite sides of an imaginary vertical plane. Nor is it any more probable that they have come up from below as igneous dikes which have intruded the sediments of the iron formation. The physical objections alone to this view are such as entirely to exclude it from serious consideration. On the other hand the phenomena of their relations to the inclosing rocks, which have been described, all lead to the conclusion that they are later concentrations, and indicate the main lines along which the concentration was brought about.

In general, this process of concentration has been a removal by circulating waters, in favorable places, of the silica of the old rock, and its contemporaneous replacement by iron oxides. This process has gone on in the contact zone, in the detrital conglomerates, as well as in the underlying jaspers. The evidence in both cases is abundant and clear. In the case of the iron formation of the lower series, the siliceous bands may be traced along the strike in all stages of replacement, until finally they are wholly represented by new iron oxides. In some cases the new iron ore is of coarser texture than the old, and so the original banded structure may still be traceable into a body of nearly pure ore. In the case of the conglomerates, we see in thin sections original rolled quartz pebbles, which are sometimes surrounded by new growths of quartz studded with iron oxides about the periphery. This process, too, may be traced through all stages, from cases in which the attack on the old pebble has just begun to those in which the quartz of the original grains is almost entirely gone. It is an interesting inquiry, upon which, however, little direct evidence can be brought to bear, as to how far the concentration in the conglomerates has depended upon the new growth of iron ore about rolled nuclei of iron sand. Bearing possibly upon the question is the fact that the crystalline plates of specular hematite are frequently and perhaps always coarser in the slate ores that occur in the contact zone than in those belonging lower down within the iron-bearing member.

The process of concentration in the Republic area has not proceeded indiscriminately throughout the iron-bearing member. The distribution of the important ore deposits shows that it has been localized in accordance with certain physical conditions. The main facts of distribution are (1) that the ore bodies occur within or not far below the contact between the upper quartzite and the iron-bearing member; (2) that they occur in pitching synclines in the vicinity of the greater orogenic disturbances; (3) the larger bodies usually have a basement of soaprock. These relations of distribution are so constant that they must be regarded as necessary conditions. It is evident that the conditions in both cases were such as to promote comparatively free circulation. In the contact zone the loose texture of the conglomerates afforded connecting open spaces through which waters could readily pass. It is equally evident that the general breaking up attending sharp folding in the underlying iron formation would not only open channels for percolating waters but would also reduce the siliceous bands to a condition in which they could be readily attacked.

From the relations which the ore deposits bear to the structure produced at the time of the later folding, it clearly appears that much of the concentration has been effected since Upper Marquette time; but it does not follow that some of the deposits were not already in existence at the time of the Upper Marquette transgression. If, as there is strong reason for believing, the specular character of the hematite of the jaspers and of the rich ore deposits of the Republic area is connected with differential movements of bed on bed, produced at the time of the latest folding, it is necessary to believe that concentration either has preceded the folding or else went on contemporaneously with it. In the case also of those deposits which are traversed by the plane of division between the upper and lower series, and so lie partly in both, the part of the deposit in the lower series may have been in existence at the time of the transgression, while that in the upper series may be partly fine débris derived from the underlying body. In both, the processes of enrichment have doubtless proceeded continuously through all subsequent time.

CHAPTER V.

GENERAL GEOLOGY.

In considering the general geology of the Marquette district we have to deal with three series: The Basement Complex, the Lower Marquette, and the Upper Marquette. These three series are separated by unconformities. The Basement Complex includes granites, gneisses, crystalline schists, surface volcanics, and various subsequent intrusives. The area south of the Marquette series is spoken of as the Southern Complex; that to the north as the Northern Complex. The Lower Marquette series, from the base upward, comprises the Mesnard quartzite, 110 to 670 feet thick; the Kona dolomite, 425 to 1,375 feet thick; the Wewe slate, 550 to 1,050 feet thick; the Ajibik quartzite, 700 to 900 feet thick; the Siamo slate, 200 to 625 feet thick, and the Negaunee iron formation, 1,000 to 1,500 feet thick. We thus have a minimum thickness for the series of 2,975 feet, and a possible maximum, taking each formation at its greatest thickness, of 6,120 feet. It is not probable than any single section will give as great a thickness as 5,000 feet. The Upper Marquette series comprises the Ishpeming quartzite, the Bijiki schist, the Michigamme formation, and the Clarksburg formation.

It is impossible to give even an approximate estimate of the thickness of Upper Marquette series, but in the district considered, excluding the volcanics, it is probably less than 5,000 feet.

Later basic igneous rocks intrude in an intricate manner both the Upper Marquette and the Lower Marquette series.

The aim of the following paragraphs is to briefly sketch the history of the district.

THE BASEMENT COMPLEX.

The oldest rocks of the Basement Complex are thoroughly crystalline foliated schists and gneisses. A close field and laboratory study has failed to detect in them any evidence of sedimentary origin. If detrital rocks, they have become so profoundly metamorphosed as to have lost all evidence of their origin. These gneisses and schists have been cut by various granites at different epochs. The granites occur both in the form of great bosses and in dikes, sometimes cutting, sometimes parallel to the foliation of the rocks. In some cases the number of intrusive belts parallel to the schistosity is so large, and they are so narrow, as to give very numerous interlaminations of schist and granite within a short distance. In the area of the Northern Complex there were volcanic outbursts, and a vast series of lavas, agglomerates, greenstone-conglomerates, and tuffs were piled up. By far the greater part of the volcanic material is of an intermediate or basic character. While the material is undoubtedly of surface origin, a search year after year in the field has wholly failed to reveal any evidence whatever of arrangement by water. The deposits are strictly volcanic. After the lava floods and vast masses of tuffs were piled up there were granitic and syenitic intrusions, for bosses of these rocks and dikes from them cut through the volcanics.

After the building up of this volcanic series, and also perhaps during this period, the region was deeply truncated, as a consequence of which many of the different varieties of rocks composing the Basement Complex appeared at the surface. The coarse granites must have formed as deep-seated rocks; the foliation of the schists must have formed far below the surface, and such rocks could only have reached the surface by long-continued denudation, which removed mountain masses of materials. The process continued until the Basement Complex had no great altitude, for before a great thickness of the Lower Marquette series was deposited the sea had entirely overridden the Marquette area.

THE LOWER MARQUETTE SERIES.

THE TRANSGRESSION HORIZON.

Toward the end of this period of denudation, the sea reached the northeast border of the Marquette district. Advancing upon it, perhaps in part as the result of depression but largely as a consequence of subaerial and marine erosion, the fragmental sediments of the Mesnard formation were laid down. This advance steadily continued from the northeast toward the southwest and west, the first deposit being everywhere fragmental sediments, at the base usually a coarse conglomerate, and higher up a sandstone which subsequently was changed to a quartzite. Long before the seashore reached the western end of the district other formations began to be deposited in the eastern half of the area, so that we have some measure of the time required for the transgression. The formations thus deposited above the Mesnard quartzite before the sea advanced to Michigamme Lake were the Kona dolomite and the Wewe slate. It follows then that in passing from the east to the west end of the area there are in the Lower Marquette series fewer and fewer formations. At the east end is the full succession; at the extreme western are only two upper members. Lithologically the whole transgression horizon is one formation, marking as it does, a continuous belt of conglomerate and metamorphosed sandstone immediately above the Basement Complex. Chronologically, however, different parts of it are to be equated with several formations, that part of it only being called the Mesnard quartzite which was deposited before the beginning of the deposition of the next higher member, the Kona dolomite, and hence it is necessary in the chronological scale to subdivide this lower conglomerate and quartzite between the various formations from the Mesnard quartzite to the Ajibik quartzite. It is not possible to do this accurately in the mapping in all places, and the manner in which one formation feathers out against the shore-line to be succeeded by the next one must be more or less arbitrary, although it so happens that there is no considerable difficulty in this particular for most of the area. The part of the district in which this arbitrary subdivision is most conspicuous is in the quartzite which occurs east of Teal Lake.

UNCONFORMITY AT THE BASE OF THE LOWER MARQUETTE SERIES.

As evidence of the unconformity between the Lower Marquette series and the Basement Complex is found all along the lower part of the transgression quartzite, the phenomena showing unconformity will be here described rather than in connection with the separate formations, among which this belt is divided. However, for the exact locations of particular contacts it will be necessary to refer to the descriptions of the individual formations.

Beginning at the east end of the south side of the Marquette district there are numerous localities from Lake Superior to west of Lake Mary where a granite conglomerate is found bearing numerous bowlders of granite, gneisses, and schist, identical with the rocks constituting the Basement Complex immediately adjacent.

In several of these localities the actual contact between the Mesnard quartzite and the Basement Complex is seen. Some distance farther to the west the Marquette formations reach the Pleistocene sand plain, the Basement Complex not being exposed. Passing this area, we next find in the Marquette series two islands of the Basement Complex in secs. 22 and 23, T. 47 N., R. 26 W. Here are found most magnificent exposures of great bowlder conglomerate and recomposed granite, resting with visible contact upon the Basement Complex and composed of material mainly derived from it. In sec. 23 the predominant rock of the Basement Complex is a peculiar white schistose granite, and the predominant bowlders of the conglomerate are of the same character. Now passing south of the Cascade Range, there are again a number of localities from secs. 34 to 32, T. 47 N., R. 26 W., where are Basement conglomerates, the great bowlders again being mainly identical with the adjacent granite, gneisses, and schists of the Basement Complex. In this area in the Basement Complex are some peculiar basic eruptives, and these rocks are found in the form of well-rounded water-worn bowlders in the conglomerate. For some distance west of sec. 32 no contacts are found, the next being in sec. 28, T. 47 N., R. 27 W., where the phenomena are similar. West of this place no actual contacts between the quartzite and the Basement Complex are found until the end of the Republic trough is reached, where again a conglomerate hangs with visible contact upon the flank of the granite, bearing well-rounded water-worn bowlders from it. Passing to the north side of the belt, and again beginning at the east, there is exposed a magnificent basal conglomerate about 3 miles west of Marquette, north of Mud Lake. Here the rocks adjacent to the Mesnard quartzite are the sheared dioritic schists, and these peculiar rocks are largely found as fragments in the basal conglomerate. There are also found granite bowlders similar to the granite masses, which a short distance to the north intrude the volcanics of the Northern Complex.

The next known contacts to the west are at the base of the quartzite east and west of Teal Lake. Here, at a half dozen places, the contact is found, the conglomerates having, as usual, as their major fragments the immediately subjacent material at the particular locality. At one place the relations are such that the layers of the conglomerate cut across the foliation of the subjacent schist at an acute angle (fig. 15). Continuing west to sec. 30, T. 48 N., R. 28 W., the quartzite is found in visible contact with the granite at a number of places (Pl. XVIII), and again its most abundant material is exactly like the subjacent granite. In some of the places here the basal rock is a conglomerate, in others a "recomposed" granite—i. e., is composed of the separate crystals of the underlying granite. West of this point the only actual contact known is north of the Michigamme mine, although at a number of places strongly feldspathic quartzites occur near the granite.

We thus have more than a score of localities scattered about the entire area covered by the Lower Marquette rocks, where occur great basal conglomerates, oftentimes resting with visible contact upon the rocks of the Basement Complex. In all of these cases the detritus is most distinctly water worn, and while the major portion of the material in each case must have been derived from the immediately subjacent part of the Basement Complex, other material not occurring in the immediate neighborhood is found, thus showing conclusively that these rocks are not Reibung's or fault breccias. The evidence is therefore demonstrative that the Lower Marquette series was deposited unconformably upon the Basement Complex.

As explained later, it will be seen that locally, as a result of the powerful dynamic action caused by the close folding to which the series have been subjected, the foliation of the Basement Complex and that of the basal quartzite is usually the same, and that at certain localities the basal conglomerate and quartzite have been so sheared as to pass into completely crystalline schists, which appear to grade down into the foliated schist or gneiss of the Basement Complex. As a consequence, the granites of the Basement Complex have been described by certain geologists as intrusive within the Lower Marquette series. Others have said that it is a case of downward-progressing metamorphism. Taking into account the above facts as to the contacts and conglomerates, there is no escape from the conclusion that this apparent conformity and gradation are illusory, being produced by the metamorphosing processes of profound dynamic action connected with metasomatic changes.

DEPOSITION OF THE LOWER MARQUETTE SERIES.

In the earlier part of Lower Marquette time, the sea steadily progressed southwestward from the northeast, and as soon as it advanced a little way upon the land the deposition of sandstones replaced that of the conglomerates. By the time the sea had transgressed as far as Teal Lake on the north and Goose Lake on the south, argillaceous and siliceous limestones began to be deposited in the east end of the district, and hence the western limit of the Mesnard quartzite is placed at these localities. The Kona dolomite probably marks deeper and quieter waters, and therefore indicates that depression had been continuing. A thin layer of slate marks intermediate conditions between those favorable to the deposition of sandstone, and those in which the limestone was deposited. However, the area of the limestone was too near shore and the water too shallow for a pure nonfragmental formation to be built up, especially as vigorous erosion still continued on the adjacent land, and hence it is that even the purest dolomite beds bear a greater or lesser quantity of nonfragmental material, while they are frequently interstratified with shale, graywacke, and quartzite. Because the sea had not yet overridden the lands of the central part of the district, the Mesnard dolomite is limited to the eastern part of the area. On the south side of the area the westernmost exposures occur at Goose Lake, and on the north side of the area the most westerly exposures which clearly belong to this formation are those at Morgan Furnace, although a belt of slates very similar to those associated with the Kona dolomite occurs interstratified with the quartzites east of Teal Lake. This belt feathers out about one mile east of Teal Lake, and suggests that here was the western limit of the shore-line at the end of Kona time.

As a consequence of the upbuilding of this formation, combined, perhaps, with a cessation of subsidence, the waters again became shallow, and there followed above the Kona dolomite the Wewe slate. The intermediate conditions favorable for mud deposits continued for some time. On the south side of the series the western limit of the shore line at this time was in the eastern half of sec. 21, T. 47 N., R. 26 W., and on the north side probably at or near Teal Lake. By the upbuilding of the beds, the waters became shallower and shallower until the waves of the sea were able to transport sand throughout the area of the district. There is evidence that in some localities the compacted mud arose above or near to the surface of the water, so as to become cut by the waves and yield fragments to the succeeding sandstone. The sandstone has been subsequently indurated to a quartzite, and hence there follows above the Wewe slate the Ajibik quartzite. During the time of the deposition of the Kono dolomite and Wewe slate the shore did not advance very rapidly, but during the deposition of the sandstone following these formations there was a rapid advance of the sea toward the west.

Erosion had been steadily wearing down the highlands and the sea had been advancing. On the north the Ajibik sandstone pushed west to Michigamme, and on the south as far west at least as the Goodrich mine. The sea gained farther upon the north than at the south, the shore-line apparently being diagonal, running in a northwest and southeast direction, still further suggesting what was said at first, that the advance of the sea was from the northeast. The subsidence continued faster than the upbuilding of the sands, so that there followed above them mud deposits, which have been compacted into the Siamo slate. During the time of mud deposits the shore-line continued to advance, and before this formation was completed the sea had entirely overridden the Marquette district with the possible exception of the southwestern part. Following naturally from the conditions of deposition, the Siamo slate has a greater thickness in the eastern than in the western part of the district, and it does not appear in the southwestern part. Perhaps equivalent to some part of the Siamo slate in time is the basal quartzite from Humboldt to Republic, but as it is impossible to say what part of the quartzite belongs with the Siamo slate and what part with the Ajibik quartzite, it is all mapped as the latter formation because of its lithological likeness to it.

The steady subsidence during the deposition of the Siamo slate increased the depth of water so that a nonfragmental formation began to be deposited. This comprises the sideritic slates, which have been largely transformed into the other varieties of rocks of the iron-bearing formation. The conditions which led to the deposition of the iron carbonate are not certain. At this time the Marquette transgression had entirely overridden the land of the district, but it is not probable that all adjacent land areas had disappeared, or even that the green schists of the Northern Complex were entirely covered by the sea, although it is possible, or even probable, that the long-continued erosion had reduced the land areas near to baselevel, and consequently that chemical solution rather than mechanical wear, was the more important agent of erosion. Thus would be explained the large amount of iron salt which appeared. Doubtless the supply of ferruginous material was in the form of iron carbonate, taken into solution by direct atmospheric agencies, perhaps with the assistance of organic acids. The basic eruptives in the Basement Complex, and especially the surface volcanics on the northern edge of the belt, are very rich in iron. These latter, being surface volcanics, were porous, and perhaps from them came the greater proportion of iron. In the water, also, there was doubtless life. As the iron carbonate came down into the open water it would be peroxidized, and the iron precipitated as hydrated oxide. When this was buried with organic matter the decomposition of the latter would produce carbon dioxide, and the iron would be reduced to the protoxide by the organic matter. The two would combine and reproduce iron carbonate. Whether the area of deposition of iron carbonate was an arm of a larger sea, an inclosed lagoon, or an inland lake, there are no means of ascertaining, but the widespread distribution of this inferior iron-bearing formation in the Lake Superior region suggests that the areas of deposition of such material were very large.

ERUPTIVES OF LOWER MARQUETTE TIME.

At one locality amygdaloids are interstratified with the Siamo slates. In others, closely associated with the Negaunee iron formation, are volcanic tuffs. It thus appears that in later Lower Marquette time there was volcanic action. Just how extensive these volcanoes were has not yet been determined, as these rocks have not in all cases been discriminated from the later igneous rocks.

UNCONFORMITY AT THE TOP OF THE LOWER MARQUETTE SERIES.

Whether any later formations followed conformably upon the Negaunee iron-bearing formation it is impossible to say, but if so they were subsequently removed by erosion. Following the deposition of the Negaunee formation and all possible later formations, the land was raised above the sea, gently folded, and eroded. In general the discordance between the Lower Marquette series and the succeeding series is not great, being measured frequently by 5° or 10°; at other times by 10° or 15°, and it is only rarely that the plications of the lower series are such as to make them abut perpendicularly against the next overlying series. In these cases the truncated layers are those of the minor plications rather than the major folds (figs. 18 and 19). Erosion cut deeper in the Lower Marquette series in some places than in others. At the east end of the area it left a very considerable thickness of the iron-bearing formation, but in places to the west this formation is quite cut out. Indeed, in places erosion cut through the Siamo slate and the Ajibik quartzite, and sometimes even into the Basement Complex, as, for instance, in the Palmer area. This particularly occurs in the west and southwest parts of the district, west of Champion and along the Republic tongue, where but few members of the Lower Marquette series were deposited. Even within a short distance the differential erosion was considerable. For instance, at the south end of the Republic tongue it was more than 1,500 feet.

To what extent the Lower Marquette series was altered during this period of folding and erosion it is impossible to say. It is probable that the upper formation, consisting of the readily altered iron-bearing carbonate, suffered the most, and there are indications that ferruginous chert and jasper were formed in the upper part of the formation. At least numerous fragments of such materials are found in the succeeding formation, and either these rocks were produced from the iron carbonate during this folding and erosion or else the iron carbonate bowlders and fragments, in common with portions of the Negaunee formation, were at a later time altered in a like manner so as to produce the same results in the fragments and in the Negaunee formation itself. It is probable that such subsequent modification has occurred to some degree, but many would doubt whether it were possible for such exactly similar changes to have occurred as to make the bowlders and fragments of chert and jasper precisely like the underlying Negaunee formation.

THE UPPER MARQUETTE SERIES.

DEPOSITION OF THE UPPER MARQUETTE SERIES.

The Upper Marquette history begins with the transgression of the sea, as a result of which the Ishpeming formation was deposited. If we may judge by the greater thickness of the Goodrich quartzite at the east part of the district, and the greater erosion of the Negaunee formation at the western end of the area, an anticline had formed to the west, and the transgression of the sea was again from the east or northeast. Thus, the Negaunee formation in the eastern part of the area would be more quickly buried. In other words, the western part of the formation was higher and was subjected to longer erosion. Also in this case in the eastern part of the district the sediments of the Ishpeming quartzite would have first begun to form. The western part of the area was still above the sea, and therefore receiving no deposits. We thus partly explain the very considerable thickness of the quartzite about the Ishpeming-Negaunee area, and its dying down to an exceedingly narrow stratum in the western end of the district.

The first deposit of the advancing sea was a conglomerate, the detritus of which was derived mainly from the immediately subjacent Negaunee formation. Hence it is that the basal formation is so frequently jasper-conglomerate, chert-conglomerate, and, when the detritus is finer, recomposed chert and jasper, ferruginous slate, etc. However, the detritus was derived not wholly from the Negaunee formation but in part from the various lower formations. This shows that either within the district under discussion or adjacent to this district the waves had cut into the inferior formations and even down to the Basement Complex. This is well illustrated by the Palmer belt of the Goodrich quartzite, where the conglomerate contains not only fragments of the Negaunee formation but of the Ajibik quartzite and of the Basement Complex.

Following the basal conglomerate which is from a few to several hundred feet thick, came a sandstone deposit. The sand was largely simple pure grains of quartz, which could not have been derived from the iron-bearing formation, but must have come from lower formations outside of the district discussed. This implies that adjacent to the district erosion by this time had removed large areas of the Negaunee formation. Mingled with the coarse simple grains of quartz are also fine complex fragments of chert and jasper, which shows that in places the Negaunee iron formation was still being cut. This sandstone has been subsequently changed to a quartzite.

Early in the time of sand deposits along the southern part of the district, an east-west fissure was formed, and a major and probably two minor volcanoes developed. As a consequence there was piled up the Clarksburg formation, a mountainous mass of material, consisting of lavas and tuffs, some of which were rearranged by water. The area over which the volcanic material was deposited gradually grew, reaching east as far as Stoneville and west as far as Champion. These more remote deposits are very much thinner, and show evidence of water arrangement. As the lavas and tuffs were piled up, subsidence, possibly due to the burdening of the land, went on, so that there resulted a great bend of the adjacent formations to the southward. How far to the south and to the north this volcano was felt, we do not know, but the slates to the north indicate that it reached to the extreme northern part of the district considered. This volcanic activity lasted for some time; for, beginning in the time of the Ishpeming quartzite, it did not cease until a considerable thickness of the Michigamme slate had been deposited. Contemporaneously with these extrusives, it is probable that intrusives penetrated the Lower Marquette series and the Basement Complex.

In the western part of the district the Goodrich quartzite grades upward into a grünerite-magnetite-schist, and this into a ferriferous slate, often sideritic. In the eastern part of the district this Bijiki schist may exist, but exposures have not shown it. As it is regarded as developing from a sideritic slate, it appears that following the deposition of the sandstone there were waters favorable to the deposition of a nonfragmental sideritic formation—that is, the conditions of the Negaunee formation of the Lower Marquette were reproduced, but not with such perfection, for the ferruginous slates in much of the district were mingled with greater or lesser quantities of mechanical sediments. This is truer for the eastern end of the area than for the western, where a considerable belt of grünerite-magnetite-schist is comparatively free from mechanical sediments, and can be mapped as a narrow separate formation.

The zone of ferruginous shales was apparently of variable thickness but it was followed above by ordinary shales, which, however, are locally ferruginous. Also with these shales was deposited a good deal of organic matter, as is shown by the fact that the resultant slates and schists are carbonaceous or graphitic, in some cases the subsequent changes not having been sufficient to destroy all of the hydrocarbons. These hydrocarbonaceous shales are particularly abundant at the horizons which are heavily ferruginous, and thus confirm the suggestion made in considering the Negaunee formation, that organic matter was instrumental in reproducing iron carbonate from the precipitated iron oxide. This ferruginous and carbonaceous shale is very similar to some of the Paleozoic shales of the Appalachians, and argues similar conditions. Subsidence must have steadily continued during the deposition of the shale, for it is of considerable thickness. The sediments vary in coarseness, as shown by the fact that the rocks now found include fine-grained slates, graywackes, and even rocks which approach a quartzite. This rock indicates waves and currents of varying strength or water of varying depth, or both. The shale and graywacke have been modified over extensive areas into mica-slates, mica-schists or mica-gneisses.

FOLDING OF THE THREE SERIES.

The Marquette district had been an area of deposition since the beginning of Upper Marquette time, and sediments of great thickness had accumulated. A physical revolution next occurred, as a consequence of which this area was raised above the sea and was folded in a complicated manner. (See Pls. XIII–XV.) Whether there was an epeirogenic movement which raised the plateau above the sea before the closer corrugations, and whether all of the different folds now found were formed simultaneously or successively, have not as yet been determined. In general, the directions of folding are approximately east and west, or north and south. The only important exception to this is in the southwest part of the district, where the Republic and Western arms swing away from the main area of Algonkian in a southeast and a south direction respectively.

The largest but least conspicuous fold of the district is an anticline near Marquette, having a north-south axis. This fold has a gentle dip, but a length of many miles gives it a great amplitude. Its effect upon the lesser but more conspicuous east-west folds is to give them a western pitch. It follows that in going west from Lake Superior the Marquette area becomes broader and broader, and higher and higher members appear in successive eastern pointed U's, the ends being, however, often crenulated, due to the folds of the second and third order. Apparently the eastern half of range 25—that is, 3 miles west from Lake Superior, is near the crown of the anticline. This great fold is by no means simple in its character, but has, especially near its crown—that is for the eastern 6 or 8 miles of the district—superimposed upon it folds of the second order, making this part of the fold an anticlinorium. These secondary folds have lengths varying from one to several miles, and therefore a given formation may be repeated in an east-west direction along the present plane of denudation. The other major anticline belonging to this system of folds is one running north and south through the east end of Michigamme Lake. From this line the Algonkian belt broadens to the east and to the west. It then follows that all of the district between the center of range 25 west and the east end of Lake Michigamme may be regarded as a great north-south syncline.

The major part of the district has been affected, however, by much more powerful pressure in a north-south direction, so that the folds in an east-west direction are much more conspicuous than the north-south fold of greater length and greater amplitude. The conspicuous character of these folds has, in fact, led to neglecting the effect of the folding in the other direction, and thus one of the most important clues to the distribution of the formation has been unnoticed. As a result of the north-south pressure, the Upper and Lower Marquette series together have been bent into a great synclinorium. At the east end of the district the Mesnard quartzite is overturned at one place and dips under the Southern Complex at an angle of 80°. The strikes of most exposures are mainly controlled by the east-west folding, but at the east and west end of the outcrops of the formations the larger north-south folds already described control the strike. In passing to the west on the south side of the area, from Lake Mary to Goose Lake and somewhat beyond, the secondary north-south folds and the primary east-west folds are of about equal amplitude, although the east-west folds are closer, and give higher dips. As a consequence of these two forces some belts strike north and south, some east and west, and some in an intermediate direction, thus giving here, at first sight, an apparently lawless distribution of the formations, but when the character of the folding is understood the distribution is perfectly explained. From the north-south line running through Goose Lake to the west line of range 28 west is the area where the Marquette series have the greatest width. For this part of the area it appears that the more rigid rocks of the Basement Complex have, as it were, been jammed under the sedimentary rocks on the north and south sides of the belts, so that the outer Algonkian formations are closely plicated into a series of overturned and in some places isoclinal folds, the dips on both the north and south sides being toward the center of the trough, and away from the Basement Complex (fig 9). These secondary east-west folds are usually only discovered by tracing the contact between two formations. In passing on the plane of denudation toward the center of the trough, one first passes from a lower formation to a higher formation; then apparently above this he may again find the lower formation, and this infolding in extreme cases is repeated several times. (Pl. XVIII.) However, upon the whole, the great syncline controls, so that finally the inferior formation is not again found. In passing inward toward the center of the Marquette area, the minor folds become more open in their character, and in the center have a symmetrical shape (fig. 9). We then have a structure in this district in some respects like the fan-shape folds of the Alps, with, however, the great difference that the area as a whole is a synclinorium instead of an anticlinorium; that is, the oldest rocks are found on the outside of the fan-shaped areas, and the youngest rocks in the center of the area.

The overfolds on the outer borders of the Marquette belt are best discovered in places where as a consequence of the pitch given by north-south folds an east or west termination of the formation appears. A few of the best illustrative areas may, perhaps, be mentioned: West of Goose Lake, in secs. 22 and 23, by reference to the map (Pl. XIII), it will be seen that there are four Archean areas, separated by Algonkian rocks both in an east-west and north-south direction. Their separation in an east-west direction is due to the secondary north-south folding, and their separation in a north-south direction is due to the isoclinal northwest-southeast overfolds. The latter folds are closer; the majority of the strikes are northwest and southeast, and the dips are all to the northeast. The fragmental formations thus appear to plunge under the Archean islands on the south sides of the areas and lie above them on the north sides. The infolded character of the Upper Marquette and Lower Marquette is illustrated by the isoclinal overfolds along the north half of the north-south quarter line of sec. 21, T. 47 N., R. 27 W. Here a north-south section at one place shows the Negaunee formation; above this in its proper position is the Ishpeming quartzite, and then there reappears above this again the Negaunee formation. At the west end of the Jackson mine also, the isoclinal overfolds of the Ishpeming quartzite and the Negaunee iron formation are beautifully shown. However, the best locality of all to illustrate the isoclinal overfolds is in sec. 30, T. 48 N., R. 28 W. (Pl. XVIII.) Here the infolding is between the granite of the Northen Complex and the Lower Marquette Ajibik quartzite and Siamo slate. A section at the most favorable place passes from the Siamo slate to the Archean granite, then again to the Siamo slate, from this to the Ajibik quartzite, into the Archean granite, in turn into the Ajibik quartzite, granite, Ajibik quartzite, granite, Ajibik quartzite, and probably following this, although topography rather than exposures indicate this, comes again the Siamo slate, the Ajibik quartzite, and the Archean for the final time. For the whole of this distance the dips are to the south. Two islands of Archean are cut off from the main area. The quartzites and slates occupy the valleys, while the granite is more resistant and occupies the higher land. Controlled by the western pitch, the tongues of quartzite which project into the Archean die out to the east, being surrounded by the granite, and open out to the west. We have here, then, the conjoint effect of the close isoclinal overfolding due to the north-south pressure, combined with the great north-south fold which gives all of the formations a westerly pitch. As for the major part of the area the north-south folds are more open, and the east-west folds more conspicuous, the latter may be designated as the direction of folding, and the former folds may be considered as giving the east-west folds a pitch.

The western major north-south anticline at the east end of Michigamme Lake causes the Marquette rocks to here contract; but to the west, in passing toward the next syncline, it opens out into the broad area of Algonkian rocks which extend beyond this district. It is rather probable that the eastward-projecting land between the west and southwest arms of Michigamme Lake marks an intermediate anticline, which, however, does not rise high enough to bring to the surface any rocks higher than the Michigamme schist. The Republic tongue and the Western tongue are closely compressed synclines which branch off from this main area in southeast and south directions.

It has been seen that the main east-west syncline has superimposed upon it secondary folds; upon these again are those of the third order, and upon these those of a fourth order, and so on, until the plications in many places are microscopic. Pumpelly's principle, that these minor folds are usually of the same character and pitch as the folds of the next order of which they are a part, has been of great assistance in working out the stratigraphy of the district.

When the formations are brittle the intense plications have resulted in their being fractured through and through, and in many places they pass into Reibung's breccias. These phenomena are particularly prevalent in the Negaunee iron formation and in the quartzites. The more plastic formations have yielded without major fracturing, but in a minor way they show everywhere the effects of deformation. A microscopical study shows that not a cubic inch of material has escaped dynamic action. Almost every original grain of fair size gives evidence of interior movement. The rocks have been kneaded throughout. While as a further consequence of dynamic action there has been local faulting at various places, with two or three exceptions no important faults have been observed in the district.

It is inferred from the above phenomena that when folded the rocks which are now at the surface were buried under a thickness of several thousand feet of sediments, not impossibly as much as 10,000 feet. While the Upper Marquette slate has at the present time in this district no such thickness as this, in the Penokee district 10,000 feet is exceeded, and it is probable that this great slate formation once extended with nearly or quite its full thickness over the Marquette district. On the other hand, it appears that the formations were not so deeply buried as to be beyond the sustaining strength of strong rocks like quartzites, or else the layers of these rocks would have been folded upon themselves without the production Reibung's breccias, as in the case of the Doe River quartzite in Tennessee. Had the rocks which are now exposed not been deeply covered, it is hardly possible that the complicated folding above described could have occurred without complicated faulting.

The only fault in the district beside that in the Republic tongue (described on pp. 619–623), large enough to materially displace the formations, is in sec. 6, T. 47 N., R. 25 W. Here in the southeast quarter of the section the Carp River flows along the line of a fault, the quartzite formation being displaced laterally some hundreds of feet. The horizontal throw is here perhaps more than 500 but probably less than 1,000 feet. How far this fault extends to the northeast and southwest the outcrops are insufficient to determine.

INTRUSIVES.

Diorites (probably altered diabases) are intrusive in both the Lower Marquette and Upper Marquette series. This is shown by bosses cutting across the bedding of the layers, by dikes branching off from the bosses and cutting the formations of both the Marquette series (Pl. XXI), and by large and small inclusions of grünerite-magnetite-schist in the diorite at the Winthrop mine and of Siamo slate at Michigamme. (Pl. XX.) As the Upper Marquette rocks are not overlain by a higher series it is impossible to determine the age of the diorites which so particularly affect the iron-bearing formation of the Lower Marquette series, but which occur within all of the formations of the district. The fact that these intrusives are of far greater abundance in the broken and fractured Negaunee formation than in the other formations, suggests that the cracks and crevices here produced by the folding gave the igneous rocks avenues of access which were taken advantage of to wedge themselves in between the rocks of the iron-bearing members, to force them aside, and thus to form great dikes and bosses of igneous material. Oftentimes they break directly across the bedding; sometimes they have produced a subordinate folding, but even in this latter case the material usually breaks across the bedding to a greater or lesser degree. In many instances there is a quaquaversal arrangement of the formations about the intrusive igneous masses which suggests that the igneous material has been intruded along the bedding of the formation, thus being essentially laccolites or batholites. At Michigamme and Humboldt the Siamo slate and the grünerite-magnetite-schist may be seen doming some of the smaller of the laccolites. (Pl. XIX.) Subsequent erosion has removed the capping iron formation from many of these larger domes and left the greenstone masses in the forms of bosses, the iron formation dipping away from them upon all sides just as do the sedimentary formations from the Henry Mountain laccolites. The major portions of the greenstones were once diabases but are now diorites. There are, however, occasional rather fresh diabase dikes in the district, and these may be contemporaneous with the igneous rocks of the Keweenawan period.

DENUDATION.

From the foregoing paragraphs it is evident that the rocks of the Marquette district were folded into mountain masses. The highest parts of the mountains probably correspond to the great north-south anticline through Marquette, and the next range in importance was probably at the western anticline at Michigamme Lake. These major uplifts must have been connected by numerous cross ridges, corresponding to the closer east-west folds. During and subsequent to the folding these mountains were cut down to an approximate plain, so that the region is at the present time merely bluffy. The highest point in the district, the so-called Summit Mountain, is 1,800 feet above the sea. The level of Lake Superior is 600 feet, so that the maximum relief of the district is about 1,200 feet. Beginning at the lake, there is a rapid rise to Negaunee, perhaps 10 miles, the average level here being about 1,400 feet. This eastern slope is a part of the great Lake Superior basin. From Negaunee to the west end of the district, that is, for much the larger part of the area, the variations in elevations are scarcely more than 400 feet. The present differences of elevation, with the exception of the eastward slope to Lake Superior, are mainly due to differential erosion. The hard rocks, whether jasper, grünerite-magnetite-schists, quartzites, conglomerates, or greenstones, occupy the higher elevations, and the soft rocks, the slates, shales, and most of the iron-formation rocks, occupy the valleys and swamps. Since the formations south of Marquette were raised higher by the eastern anticline, and the whole district has been truncated to an approximate plain, it follows that in the eastern end all but the lowest formations have been removed. Thus south of Marquette we find only the two lowest formations of the Marquette series. In the great syncline between the Marquette anticline and the Michigamme anticline, newer and newer formations come in, until the highest member of the Upper Marquette series appears. The Michigamme anticline apparently was not so high as the Marquette anticline, and therefore the higher members of the formation are exposed. However, we can not be sure that several of the remaining Marquette formations would not have been removed were the plain of denudation 600 feet lower—that is, at the elevation of Marquette.

METAMORPHISM.

The various formations of the Marquette series differ from one another in hardness and coarseness of grain. It is probable that metasomatic and cementing processes had taken place to some extent before the folding, and thus they probably differed in strength. When the period of folding occurred this varying texture and strength was an important factor, so that the readjustments necessary in the folding took place in large measure between the different formations and between dissimilar beds of the same formation. As these layers were rubbed over one another in many places schistosity was developed parallel to the bedding. The unconformable contact between the Upper Marquette and Lower Marquette was perhaps the greatest plane of movement, and adjacent to it the rocks of both were sheared. The contact between the Archean and the Lower Marquette series was another such shear plane, and often a considerable zone at the base of the Lower Marquette series was transformed into a schist, as was also a zone of the rocks of the Archean immediately below. When the lower quartzite was thin, as in the Republic tongue, this change affected the entire basal formation. In other places, where the folding was less severe, the rocks still plainly show clastic characters.

These statements as to the adjustment between the layers and the development of schistosity parallel to the bedding do not apply to such an extent to the Michigamme and other slates. There apparently occurred in these formations an actual mashing, the whole acting in a way as plastic material; consequently there is frequently a discrepancy between the cleavage or schistosity and the bedding. Oftentimes it happens that the schistosity corresponds with the bedding on one side of a fold and cuts across it upon the other (fig. 17). In this case the complicated character of the folding and the reduplications of the beds are particularly likely to be overlooked. In the crystalline rocks constituting the Basement Complex the north-south pressure was the predominating force, and a nearly vertical schistosity has been extensively developed with an approximately east-west strike. This is particularly conspicuous in the case of the volcanic rocks. Here the same principle of homogeneity has applied, as in the Michigamme slate. The whole mass was mashed together, and flowage resulted in nearly parallel schistosity.

During the time in which the dynamic forces were at work—that is, while the folds, cleavage, and schistosity were forming—chemical and molecular forces were actively at work, and from the old minerals new minerals were developing. Also other mineral material was being deposited in the interstices. Thus we have quartzites or quartz-schists in place of the sandstones; slates, graywackes, mica-slates, mica-schists, or mica-gneisses in place of the shales and arkoses; and the peculiar phases of rocks of the iron-bearing formation in place of the sideritic slates.

In so far as the rocks have a strongly developed schistose structure, it is believed that the metamorphism was contemporaneous with the folding, but during the long period of quiescence which has subsequently occurred, further extensive metasomatic and weathering changes have taken place. These appear to have been particularly potent in the iron-bearing formation, but they have also doubtless produced important changes in other rocks. In this time of quiescence must have occurred the final enrichment of the ore bodies and the extensive impregnation of the various rocks with the unsheared hematite and magnetite. It is also possible that the metasomatic processes which produced the grünerite-magnetite-schists, ferruginous cherts, and jaspers, were more powerful at this time than during an earlier period.

Finally during this period of quiescence it is believed there developed much of the garnet, staurolite and andalusite, and the secondary feldspar of the mica-schists and mica-gneisses.

CORRELATION.

Reasons have been given in a previous publication for regarding the Upper Marquette and Lower Marquette series together as the equivalent of the Huronian of the north shore of Lake Huron. These will not here be repeated, nor will the argument be repeated for placing the Upper Marquette and Lower Marquette as the equivalent of the Upper Huronian and Lower Huronian of the other parts of the Lake Superior region.[1] Accepting these conclusions this implies that the Lower Marquette series is to be equated with the Lower Felch Mountain and Lower Menominee series.

Smyth has recently mapped in detail an area between and nearly connecting the Marquette and Menominee districts. He has made also a general study of the latter district. As the results of his studies he summarized the Lower Menominee succession as follows:[2]

Avoiding minute subdivisions the Lower Menominee consists of—

(1) A basal quartzite, rarely conglomeratic. The thickness may reach a maximum of about 1,000 feet, and over large areas is at least 700 feet.

(2) A crystalline limestone which averages about 700 to 1,000 feet in thickness. On the Fence River in Ts. 44 and 45 N., R. 31 W., where it largely if not entirely replaces the lower quartzite, the thickness attained, if there are no subordinate folds, is from 1,500 to 2,000 feet.

(3) Red, black, and green slates that are not known to exceed 200 to 300 feet in thickness. The slates here and there contain the iron formation that affords the rich ores of Iron Mountain and Norway. In the southern part of T. 44 N., R. 31 W., the horizon of the slates is in part occupied by altered eruptives that rapidly increase in thicknesss toward the north, the whole attaining a maximum of nearly 2,000 feet on the Fence River in T. 45 N., R. 31 W.

(4) The highest member, except volcanics, yet recognized in the Felch Mountain and Fence River divisions of the Lower Menominee is typically developed at Michigamme Mountain, sec. 4, T. 43 N., R. 31 W., and sec. 33, T. 44 N., R. 31 W., and has been called the Michigamme jasper. This is a greatly altered ferruginous rock usually carrying apparently fragmental quartz grains. Various stages in the alteration permit two or three types to be recognized. The least modified seems to indicate that the rock was originally in part at least a clastic sediment. The alteration appears to have been effected by the infiltration of iron salts, the formation of cherty silica, and the replacement of the original constituents to varying degrees. The most highly altered type bears the closest possible resemblance in the hand specimen to the banded specular jasper on the Republic Bluff.

Smyth then makes the following statement as to the Marquette district:

The Lower Marquette series in the western part of the Marquette area, where it most nearly approaches the Menominee region consists, when exposed, of—

(1) A basal conglomerate (quartzite), quartz-schist, probably less than 100 feet thick. North of the Michigamme mine the quartzite passes upward into a slate.

---

[1]Correlation Papers, Archean and Algonkian, C. R. Van Hise; Bull. 86 U. S. Geol. Surv.

[2]The Lower Menominee and Lower Marquette Series in Michigan, by H. L. Smyth; Am. Jour. Sci., 3rd ser., Vol. XLVII, 1894, pp. 216–223.

(2) An iron-bearing formation which may be divided further into a lower member, composed of actinolite (or grunerite), magnetite, and silica, one or two of which may locally predominate over the rest, and an upper member usually, but not invariably, characterized by bands of red jasper and specular hematite. The iron-bearing member has a maximum thickness of more than 1,000 feet, but usually it has been cut down greatly, or with the lower quartzite entirely, by the Animikie transgression.

The Marquette iron ores, except those on the Upper Marquette series, occur, as Van Hise has shown, either (*a*) at the contact of the lower iron-bearing member with the upper quartzite, when the ore may be either a concentration in the lower iron-bearing member or a detrital member of the upper series, or, (*b*) more rarely, entirely within the iron-bearing member of the lower series.

These descriptions are expressed briefly in the following table, in which the members of the two series are shown in parallel columns for lithological comparison:

Menominee.	*Marquette.*	
Michigamme jasper	Jasper banded with ore.	Iron formation.
Slates (principal iron formation)	Magnetite-actinolite schist.	
Limestone	Quartzite.	
Quartzite		
Archean	Archean.	

Smyth traces the magnetic Michigamme jasper to within 1½ or 2 miles of the iron-bearing formation of the Marquette series, and he regards the two as equivalent. Toward the north the Michigamme jasper is found to have a lower quartzitic portion, which he places as equivalent to the lower quartzite of the Marquette district.

The whole of the Lower Marquette series would thus be represented by the highest member of the Lower Menominee. What, then, becomes in the Marquette district of the great thickness of limestone, quartzite, and eruptives which lie below the Michigamme jasper in the Menominee, and how is its absence to be accounted for?

The most probable explanation is that the pre-Algonkian basement sank continuously in both districts, but that the Marquette was initially the more elevated, and as a whole was dry land, while the lower quartzite, limestone, and slates were going down in the Menominee. The transgressive movement from the south reached it when the lower portion of the Michigamme jasper was being deposited.

In this succession Smyth includes under the name Menominee the area which has heretofore been called the Menominee district, and the large connecting area to the north, which is as yet undeveloped, is drained by the Michigamme River, and to which I have consequently given the distinctive name Michigamme district.

The chief point upon which more evidence is necessary is that the slates bearing the rich iron ores in the Menominee district are equivalent to the slates bearing the volcanics farther north in the Michigamme district. If these slates are different from those to the north and belong below them, the parallel ascending succession in the two districts would be very closely analogous. Using the succession for the entire Marquette district which we have made out, and comparing it with Smyth's succession in the Menominee district, we have the following parallel descending succession:

Upper Marquette.	*Upper Menominee.*
——UNCONFORMITY.——	
Lower Marquette.	*Lower Menominee.*
Negaunee iron formation, 1,000 to 1,500 feet	Michigamme jasper. Slates bearing rich ores.
Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick Ajibik quartzite, 700 to 900 feet Wewe slate, 550 to 1,050 feet	Slates and altered volcanics, maximum thickness, 2,000 feet.
Kona dolomite, 550 to 1,375 feet	Crystalline dolomite, 700 to 1,000 feet.
Mesnard quartzite, 100 to 670 feet	Basal quartzite, 700 to 1,000 feet.

The succession for the lower series would thus be very closely parallel in the two districts, with the following exceptions:

(1) The Wewe slate, the Ajibik quartzite, and the Siamo slate are placed opposite one member of the Menominee series. These three formations are, however, all fragmental, and are equated with a fragmental formation. Together they mark a time of mechanical deposition in each district between the nonfragmental limestone and the nonfragmental iron formation, and thus include the physical change involved in passing from a nonfragmental to a fragmental, and then again to a nonfragmental formation. The chief difference is that in the Marquette district two layers of mud were separated by a layer of sand. Another difference is that in the Menominee district volcanics are much more important, and this may account for the absence of conditions favorable to sand deposits. However, it is interesting to note that amygdaloids are found in the Lower Marquette series in the Siamo slate—that is, toward the higher part of this great fragmental formation. The Fence River volcanics in the Michigamme district occupy a similar horizon.

(2) The pure, nonfragmental iron formation of the Marquette district is equated with slates bearing the rich ores of the Menominee district and the Michigamme jasper. The only substantial difference, however, is that in the Menominee and Michigamme districts both the slates and the jasper bear, with the nonfragmental, a considerable amount of fragmental material. In other words, the conditions in these districts were not favorable to pure nonclastic sediments as they were in the Marquette district.

As there thus seems to be closely parallel successions in the three districts in early Marquette time it seems highly probable that the western part of the Marquette district, where the lower members of the series do not appear, must have been a high area almost surrounded by water, since the lower members of the series were deposited to the southeast and northeast. This headland included the area west of Ishpeming and Negaunee to Lake Michigan, and thence south to Republic. How much farther it extended to the west, and whether it was an island or a peninsula, it is yet too early to venture an opinion.

Until more detailed studies are made of the Upper Huronian rocks in the Michigamme and Menominee districts it is unsafe to attempt a detailed correlation of the formation of the Upper Marquette series with those there found. In all the areas there are certain general likenesses. The basal formation in each district is frequently an ore and jasper conglomerate, which passes up into a quartzite. In both the Marquette and Menominee districts, not far above this quartzite, near to or associated with the slates, is an iron-bearing formation. The predominant formation was a shale, which has been metamorphosed to a mica-slate or mica-schist.

THE ORIGIN AND RELATIONS

OF

CENTRAL MARYLAND GRANITES.

BY

CHARLES ROLLIN KEYES.

WITH AN INTRODUCTION ON THE GENERAL RELATIONS OF THE GRANITIC ROCKS IN THE MIDDLE ATLANTIC PIEDMONT PLATEAU.

BY

GEORGE HUNTINGTON WILLIAMS.

CONTENTS.

ILLUSTRATIONS.

ERRATUM.

Page 692. Below title of Pl. XXXVI, which faces the page mentioned, for "by G. H. Williams" read *by Charles R. Keyes.*

GENERAL RELATIONS OF THE GRANITIC ROCKS IN THE MIDDLE ATLANTIC PIEDMONT PLATEAU.

By George Huntington Williams.

PREFATORY.

The central portion of the great crystalline belt which extends along the eastern flank of the Appalachian Mountain system has received the designation of the Piedmont Plateau. The portion of this region lying in southern Pennsylvania, Maryland, and northern Virginia has been particularly studied by the writer, who finds that it shows a constantly increasing degree of crystalline structure toward the east. Its western boundary is formed by the fossiliferous blue limestones of the Frederick Valley. The crystalline region is itself divisible into two portions of about equal width, the western of which consists of a series of plainly sedimentary and but slightly metamorphosed, nonfossiliferous rocks. The eastern half of the region, though not sharply defined from the western part by any line, bears less distinct evidence of sedimentary origin. Its rocks are wholly crystalline; their structure planes are largely the result of secondary processes, while their microscopical structure bears no evidence of clastic origin.[1] Within this eastern or holocrystalline division there are great numbers of igneous rocks, which have been intruded into the preexisting masses either at the time of or subsequent to their metamorphism. In spite of the absence of definite clastic structures, the presence of beds of limestone and quartz-schist indicates that these formations were, in part at least, sedimentary, and hence, in lack of any evidence to the contrary, they are assigned to the Algonkian horizon, as this term has been defined by the U. S. Geological Survey.[2]

Elaborate and detailed work in many regions most favorable for the study of very ancient, nonfossiliferous, and highly crystalline terranes has demonstrated an extraordinary complexity of structure. Relations which at first appear to be relatively simple have been found,

[1] On the twofold division of the Piedmont Plateau in Maryland, see Bull. Geol. Soc. Amer., Vol. II, p. 301, 1890.

[2] Van Hise: Bull. U. S. Geol. Survey No. 86, p. 493, 1892.

upon minute examination, to be greatly complicated and disguised by faults, thrusts, close foldings, shearings, and foliation not at first suspected. It has been found that the greatest perseverance, the most favorable exposures, and mapping on a very large scale are necessary for a complete deciphering of the obscure record. The results obtained in the Alps, the Scottish Highlands, Scandinavia and Finland, the Green Mountains, Marquette, and Canada are a sufficient demonstration of this statement.[1]

The Middle Atlantic portion of the Piedmont Plateau is by no means as favorable to the study of the complexities of ancient crystalline rocks as the regions above enumerated. The general outlines of its structure indicate that it represents the remains of a vast and very old mountain range, the eastern half of which has sunk along a great fault beneath the sea, and thus been buried by the comparatively recent Coastal Plain deposits. What we now see is the western flank of this range, composed of early Paleozoic strata, which become more and more crystalline as they approach the central core, where they are altogether replaced by still more ancient rocks, a large portion of which are of igneous origin. We must further conceive of the region as being deeply eroded, so as to present a kind of mountain-root structure. The difficulties of the problem are thus seen to be very great even were the rock exposures all that could be desired, but this, in fact, is far from being the case.

The rocks are for the most part much decayed, while extensive cultivation has rendered exposures relatively few and unreliable. Only along the excavations made by the deepest streams, and in occasional artificial exposures, can the rock be found sufficiently fresh to make its field relations thoroughly certain. If, then, in similar greatly disturbed and metamorphosed regions the most favorable conditions and the largest-scale maps are requisite for completely making out the structure, in an area as unfavorable as that here under consideration, where the maps are on a much smaller scale, a complete deciphering of the structure as a first step is hardly to be hoped for.

While structural maps are to be regarded in this, as in all regions, as the ultimate goal of geological investigation, areal and petrographic maps must serve as a means of reaching it. While they may not express age correlations or underground structure, they will exhibit a genetic differentiation of the materials, while the general lines will sug-

[1]Peach, Horne, and others: Quart. Jour. Geol. Soc., Vol. XLIV, p. 378, 1888.
Heim: Mechanismus der Gebirgsbildung, 1878.
Baltzer:
Reusch: Bommelöen og Karmöen, 1888.
Sederholm:
Pumpelly, Wolff, Dale, and Putnam: Mon. U. S. Geol. Survey, Vol. XXIII.
Van Hise:

[NOTE.—The incompleteness of several footnotes appearing in this paper is due to Professor Williams's untimely death, which occurred July 12, 1894. It has been thought better not to attempt to perfect any of them, for while this would not be difficult in some cases, in others it might lead not only to doubt but to error.—EDITOR.]

gest a clue to the real structure. In large but poorly exposed areas of highly crystalline and greatly metamorphosed rocks, the first step must be to separate those petrographic types which best retain their individuality. Under extreme conditions of metamorphism, rocks of the most diverse origin tend to become more and more alike. Limestones, quartzites, and certain types of igneous rocks preserve their characteristic features longest, while argillaceous sediments tend to assume a close resemblance to certain igneous types from which their material may have been derived.

In a region so much disturbed and metamorphosed that the ordinary stratigraphical principles of sequence, superposition, and unconformity can not be directly applied, it becomes necessary to establish, as far as possible, by a detailed study of their contacts, of their respective degrees of metamorphism, etc., first, the origin of the different rock types; second, their relative ages.

In his work within the central portion of the great Appalachian crystalline belt, the writer has had frequent occasion to insist upon the presence of more or less disguised igneous masses, and to dwell upon the methods by which they may be recognized. Recently he has also pointed out that an important step in the differentiation of this belt may be made by the separation of the abundant surface volcanic material, which is also widely distributed along its entire extent from Newfoundland to Alabama.[1]

Within the eastern or holocrystalline portion of the Piedmont Plateau in Maryland, rocks of igneous origin are particularly abundant. While some of these show very little indication that they have been affected by dynamic action subsequent to their solidification, others, which must be much older, have been more or less completly disguised by the intensity of such subsequent changes. Within this region igneous rocks of intermediate (gabbro) and ultrabasic (peridotite and pyroxenite) composition have been already separated.[2] The acid rocks, which are much the most abundant of the igneous types, have presented greater difficulties because of the resemblance they bear to the surrounding gneisses. The present paper by Dr. Charles R. Keyes, formerly fellow in geology at the Johns Hopkins University and now State geologist of Missouri, is an attempt to demonstrate the igneous and intrusive origin of certain of the youngest and hence the least metamorphosed granites. It was undertaken at the writer's suggestion, and embodies the result of a large amount of field and laboratory study. The evidence adduced is altogether conclusive for the rocks treated of, while the conclusions are also of great value in their bearing on the older and more foliated granites of the same region, whose resemblance to the surrounding gneisses often becomes a source of much embarrassment.

---

[1] Journal of Geology, Vol. II, pp. 1–34, 1894.
[2] Bull. U. S. Geol. Survey No. 28, 1886; American Geologist, Vol. VI, pp. ——, 1890.

As an introduction to this paper, it has seemed advisable to set forth certain general conclusions relating to the acid igneous rocks of the central Piedmont region which have been derived from a somewhat longer study and broader survey of the whole field.

CRITERIA FOR THE RECOGNITION OF ANCIENT PLUTONIC ROCKS IN HIGHLY METAMORPHOSED TERRANES.

Since it is a matter of such fundamental importance in the deciphering of a crystalline region to decide as far as possible to which of the great genetic classes—igneous or sedimentary—the different rock types belong, it will be well to examine the criteria for this distinction, and to see how long they hold good. In crystalline areas which have remained undisturbed by great earth movements the essential difference between igneous and aqueous rocks remains plain and unmistakable for an indefinite time. In regions of great dynamic action, on the other hand, the characteristic features of these two great classes of rocks grow more and more indistinct, and finally, one by one, disappear. Intense pressure and shearing tend to impart to members of each of these two originally diverse groups features which belong to the other. Igneous rocks become foliated and banded, while sedimentary beds become crystalline, until at last even the fundamental distinction of origin can no longer be made with certainty, and members of both classes become merged into the group of metamorphic schists, whose original nature must perhaps always remain in doubt.

In the axes of mountain chains where crystalline rocks are developed, as well as in all truly Archean regions which have suffered little disturbance, masses of granitic composition are enormously abundant. These have been by some investigators, like Lawson[1] and Reusch,[2] regarded as sediments re-fused in situ, but most authors have now come to consider them as truly eruptive (exotic) granites. The age relations of such rocks are best studied in those oldest regions of the globe which have been but little disturbed, as, for instance, in Scandinavia and Canada. Heim says that no general petrographic sequence can ever be made out for the crystalline schists in a region of great orographic movement like the Alps, because the repeated and intense dynamic metamorphism has so completely disguised not only the relations of the rock masses to one another but also their original character.[3]

In the ancient crystalline mountain axis of the central Piedmont Plateau certain of the granitic rocks are younger than the time of principal folding and metamorphism, while others appear to be altered by dynamic action only to a relatively small degree. Hence, we are

[1] Am. Jour. Sci., 3d ser., Vol. XXXIII, p. 473, June, 1887; Études sur les schistes cristallins, International Geological Congress, London, 1888, pp. 75–88.
[2] Bömmelöen og Karmöen, English Summary, p. 422, 1888.
[3] Études sur les schistes cristallins, International Geological Congress, London, 1888, p. 20.

able to trace the proofs of eruptive character backward from the unaltered types by gradual transitions to those in which they are no longer plainly discernible.

The evidence upon which the recognition of the igneous origin of rock-masses in ancient crystalline regions depends is in part derived from their field relations, which appeal more directly to the general geologist, and in part depends upon chemical and microscopical features, which, though not so apparent to the general student, appeal no less strongly than proofs of the first kind to the special student of petrography.

FIELD EVIDENCE.

The existence of dikes or apophyses which project outward from the main mass and cut abruptly across the strike of adjoining rocks, inclusions of irregular fragments of foreign rocks, and the existence of distinct zones of contact metamorphism, are usually regarded as conclusive proofs of igneous origin. In regions of intense dynamic metamorphism, however, even these characteristic proofs become obscured or obliterated, while in this country of ultrametamorphic ideas the very evidence which indicates an igneous origin has been used as an argument for the production of these rocks by extreme softening and recrystallization of originally sedimentary beds.[1]

While radiating dikes or apophyses do not necessarily accompany all plutonic masses, their presence is generally satisfactory evidence of the origin of the main mass to which they belong. Even these, however, are not accepted by all geologists as satisfactory proof of eruptive origin, but are explained as the result of later segregation, especially if they are very coarse grained in their texture.[2] Such a set of radiating dikes may, under the influence of extreme pressure metamorphism, be reduced to a comparatively parallel system of bands which closely resemble in structure certain gneisses.[3] Again, an igneous mass often penetrates the surrounding rocks in the direction of their bedding or foliation, as this is the line of least resistance. The result of this is the production of a more or less finely banded rock, which has been called an injection-gneiss. Such cases have been described by Michel Lévy,[4] Teall,[4] Lehmann,[4] Sederholm,[4] and others.

An excellent example of such an injection-gneiss occurs on the lower Gunpowder River, north of Baltimore. The ancient hornblende-gneiss, probably itself a metamorphosed and foliated gabbro, has been intruded along the lines of its foliation by narrow bands of a reddish granite, which are offshoots from a large granitic mass lying somewhat farther north. Above the point where the Philadelphia road bridge crosses the Big Gunpowder, granitic dikes of normal character are seen inter-

[1] Van Hise: Bull. U. S. Geol. Survey No. 86, p. 488, 1892.
[2] Hunt: Chem. and Geol. Essays, chap. —.
[3] J. Lehmann.
[4] [See note at foot of p. 658.]

secting the dark rock; but as the stream is followed below this point toward the Baltimore and Ohio Railroad bridge, these granitic intrusions increase rapidly in number and conform more and more closely to the foliation of the inclosing gneiss. Just above the railroad bridge, there is a fine exposure which shows that subsequent to the production of the banded injection-gneiss the rock was greatly folded and crumpled, producing an effect similar to that described by Sederholm as "Adergneiss.[1]" (See Pl. XXVII.)

Inclusions of irregularly shaped fragments of various foreign rocks, especially if these show differences in composition and texture and have been affected by contact action, form the second class of satisfactory field evidence of eruptive origin. While for most geologists such foreign inclusions are conclusive, the rocks in which they occur have been interpreted by some of the extreme members of the metamorphic school as softened and recrystallized conglomerates in which, while the matrix has been entirely altered by so-called "selective metamorphism," the original pebbles or bowlders have not been obliterated.[2]

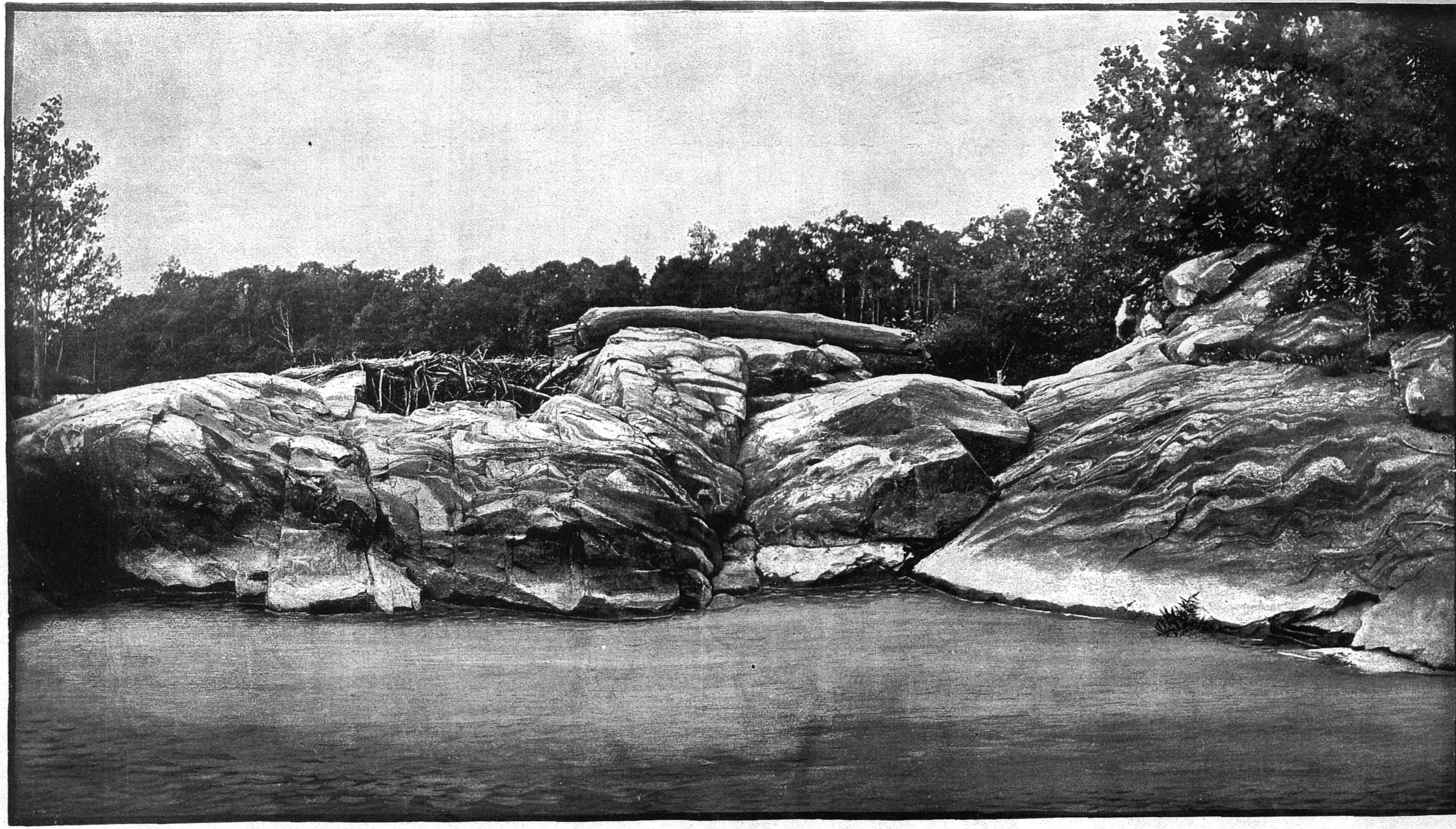
In the progress of the dynamic metamorphism of igneous rocks, inclusions of this sort become foliated along with the mass in which they are embedded, and may finally so far lose their individuality as to resemble closely other darker or lighter patches which may have an entirely different origin. We know, for instance, that basic secretions are a common feature of slowly solidifying granitic magmas, while a partially solidified portion of such a mass may be broken into and brecciated by a subsequent intrusion of the residual magma, whose composition has slightly changed, thus producing a sort of protoclastic structure.[3] In still other cases a spheroidal arrangement of the more basic constituents of the granite, as in the case of the well-known rock from Craftsbury, Vt., and other orbicular granites, may produce similar oval patches. It will readily be seen that fragments differing in composition from the inclosing granite, whatever be their origin, whether foreign inclusions or secretions from the magma itself, will, when metamorphosed, come finally to look so much alike as to be indistinguishable. The most reliable evidence of the indigenous origin of such dark patches will be found in their uniform composition and their general chemical and mineralogical relationships to the rock which incloses them. Any great diversity in petrographical character among the inclusions, any great irregularity in their size or angularity in their shape, and any zonal banding which follows their external contour, may be regarded as strongly indicative of their derivation from some foreign source.

---

[1] [See note at foot of p. 658.]

[2] Alexander Winchell: Amer. Geologist, vol. 3. p. 158 et seq., 1889. Van Hise: Bull. U. S. Geol. Survey No. 86, p. 480, 1892.

[3] This is the equivalent of the *Primärtrümmer* of Lossen, of the *Schlieren* and *Schlierengänge* of Reyer, and of the *Primärbreccia* or *Eruptivbreccia* of Sederholm.



FOLDED INJECTION GNEISS, GUNPOWDER RIVER.

The existence of distinct contact zones which follow the periphery of an igneous rock-mass, while itself very satisfactory evidence of origin, is the least common and the least persistent of all the classes of field evidence to be found in highly crystalline and much metamorphosed regions. The reasons for this are, first, that such contact zones can not be produced in rocks already highly crystalline, except to a very slight degree; second, that if they were once produced in characteristic form in sedimentary beds, they would be obliterated by the more intense dynamic changes which accomplish the general metamorphism of the entire district. While contact zones in their most typical development possess certain features which distinguish them from the products of dynamic metamorphism, many of the new minerals produced within them are also produced by the other cause. Hence, even when it is not completely obliterated, the recognition of such contact action in highly crystalline districts is generally a matter of doubt.[1]

CHEMICAL AND MICROSCOPICAL EVIDENCE.

While not such definite stoicheiometric compounds as minerals, igneous rocks have nevertheless been found to obey certain chemical laws in their composition. If they crystallize from a molten magma, they can vary only within a certain range. Such a magma has also been found in process of time to split or differentiate itself, in accordance with chemical laws, into different portions having definite chemical relationships to one another. The products of these differentiated portions must therefore be associated in the rocks occurring within a single petrographical province. Inasmuch as the evidence thus far accumulated tends to show that, even in spite of the most intense metamorphism, there is relatively little change in the bulk composition of a rock, its chemical aspects may often be used as a safe guide to its origin. As Rosenbusch has pointed out, sedimentary deposits present a decided contrast to rocks of igneous origin in the indefinite character of their bulk composition. Since they are the result of purely mechanical processes, their chemical composition is governed by accident. If, then, the chemical change produced by metamorphism is in all cases slight, we may find a clue to the origin of a given rock in its composition when all other indications fail. If this composition conforms to any well-recognized igneous type, it is probable that the rock in question was an eruptive, for, although there would be nothing to prevent a sedimentary bed from having this composition, the chances would be greatly against such a result. On the other hand, if a crystalline rock differs very widely from any well-recognized igneous type, we have

[1] The director of the Canadian Geological Survey is not willing to regard even the most typical contact zones as any indication of the igneous origin of the granitic masses which they surround. Ells describes such occurrences, accompanied by radiating dikes in the eastern townships, but Dr. Selwyn considers both the granite and the contact zone as the result of the same metamorphic process, while he considers the radiating dikes to be segregation veins. Annual Report of Canadian Geological Survey, 1886, J, p. 136.

reason to believe that it was originally a sedimentary deposit. Rosenbusch has applied this principle to the large series of analyses of gneisses taken at random, and finds that some of these agree with unaltered igneous rocks in compositions, while others show no chemical relationship to them. He therefore concludes that while members of the first class are probably foliated eruptives, the members of the second class are highly metamorphosed sediments.[1] It is therefore plain that the chemical composition of crystalline rocks, their association with other types, and their gradation into related petrographic facies, all afford valuable indications of their original character.

The mineral composition and structures of crystalline rocks, as well as their chemical relations, affords a valuable clue to the material from which they have been derived. Although in the process of metamorphism new minerals and new structures are developed which, in extreme cases, quite obscure the original components, these nevertheless persist, in traces at least, much longer than would be supposed without a careful microscopic examination. In the hornblende-schists of the Menominee and Marquette districts on Lake Superior, traces of an original diabase structure were found in spite of an almost complete recrystallization of the original rock.[2] We further know that certain silicate minerals, whose number is relatively limited, are characteristic of igneous rocks, and we likewise know into what other minerals these commonly change in the process of metamorphism. Certain other silicates, on the other hand, are especially characteristic of metamorphosed sediments, such as clays and limestones, and these minerals, as a rule, do not occur in igneous rocks, either in their unaltered or their metamorphosed condition. While, therefore, some metamorphic minerals are common to both of the great genetic classes of rocks, others, so far as we know at present, may be relied upon in this respect as tolerably certain guides.

APPLICATION OF THESE CRITERIA TO THE GRANITIC ROCKS OF MARYLAND.

To many of the granitic rocks which are so abundant in the eastern or holocrystalline portion of the Piedmont Plateau in Maryland, all the above classes of evidence are applicable, except perhaps contact action. In the youngest granites whose essential characters are best preserved, the following descriptions of Dr. Keyes will disclose abundant proof of igneous and intrusive origin. Radiating dikes and apophyses, typical eruptive contacts like that at Dorsey Run, included fragments of foreign rocks which have been more or less metamorphosed by heat, chemical and mineral composition and structure, petrographic gradations and facies, all agree in pointing to this as the only tenable hypothesis. In

[1] Zur Auffassung der chemischen Natur des Grundgebirges. Tschermak's Min. u. Petrog. Mitth., vol. 12, p. 49, 1891.

[2] Bull. U. S. Geol. Survey No. 62, p. —.

some cases, as for instance in the Sykesville area, an incipient foliation has been produced by dynamic action, which gives the rock a slightly gneissoid appearance, without, however, obscuring in any way the abundant inclusions of foreign material. In certain older granitic areas not especially considered by Dr. Keyes, the dynamic metamorphism has progressed much further. In the great belt of granitic rocks which forms the axis of the Blue Ridge between Point of Rocks and Harpers Ferry, the foliation is more pronounced than at Sykesville, although the intrusive character of the mass is still plainly shown at its contacts. In the Port Deposit region, on the Lower Susquehanna, the granites, which at Rowlandville are quite massive, become plainly foliated by the parallel arrangement of the mica in discontinuous layers. This rock, which is commonly regarded as a gneiss, has been recently studied and its igneous character established by Mr. G. P. Grimsley.[1]

As we pass from the Port Deposit granite-gneiss to the other rocks of this belt having a similar granitic composition, but a much more gneissoid structure, the evidence of igneous origin becomes more doubtful. The study of the instances above mentioned where the evidence is conclusive, leads one to the conclusion that many of the gneisses which compose the eastern crystalline belt are of a similar nature, although most of their original characters have been obliterated. This is especially true in regard to the wide belt of granitoid rocks which emerge from below the sands and gravels of the Coastal Plain south of Laurel. These rocks, though typical gneisses in their structure, are filled with what seem to be inclusions of foreign rock, especially of vein quartz and irregular fragments of similar though older gneisses. They may best be studied along the Potomac, between Washington and the Chain Bridge, where they are extensively exposed in the great quarries. They are also typically shown near the north end of Analostan Island, at the Falls of the Patuxent west of Laurel, and along Sligo Branch, Piney Run, and the lower portions of Rock Creek, near Washington. They may also be seen to advantage where Four Mile and Holmes runs have cut deeply into the Coastal Plain deposits in Fairfax County, south of Washington. In specimens collected on Sligo Branch, the surface of this rock was covered with small nodules, which upon examination proved to be made up almost entirely of quartz and sillimanite—a mineral combination strongly suggestive of the contact metamorphism of included fragments. While there is perhaps not enough evidence to settle finally the igneous origin of these gneisses, the existence of these indistinct and often doubtful inclusions, together with their bulk composition, which is that of a normal granite, points strongly to this hypothesis as the most probable. Still other gneisses which show even less indications of igneous origin than these may nevertheless be genetically closely associated with them, and owe their present features to the long-

[1] Cincinnati Journal of Natural History.

continued dynamic action which has finally succeeded in obliterating all positive evidence of their original character.

Other members of the crystalline belt, on the contrary, show, either by an alternation of comparatively thin beds of different composition or by the presence of such typically metamorphic minerals as kyanite, sillimanite, andalusite, staurolite, tourmaline, and garnet, unmistakable evidences of sedimentary character. Rocks of this sort, which are apt to be very rich in mica and proportionately poor in feldspar, occur at various localities, such, for instance, as Owings Mills, along Western Run below Ashland, and on the west side of the Port Deposit granite, but no definite relation between them and adjoining masses of igneous rocks has as yet been made out.

Between these two classes of rocks whose igneous or whose sedimentary origin may be regarded as established stands the great mass of gneiss which composes the main part of the eastern or holocrystalline belt, with respect to whose origin no positive assertion can be made with the knowledge we at present possess.

DISTRIBUTION AND RELATIVE AGES OF IGNEOUS GRANITES IN THE APPALACHIAN CRYSTALLINE BELT.

Plutonic rocks of all kinds are abundant throughout the whole extent of the crystalline belt along the Atlantic seaboard. They are of all ages down to the close of Paleozoic time. None of the truly plutonic rocks are, however, demonstrably younger than the end of the Carboniferous, when the great folding occurred which elevated the Appalachian mountain range. Some of them doubtless accompanied this great orographic disturbance, while many others are much older.

Among these rocks granites are the most abundant. These have been studied and described at many localities, but as a rule only those have been regarded as granites which are quite massive in their structure. No special effort has been made to establish the igneous origin of those which have been much foliated or metamorphosed by dynamic action. It is probable that throughout the belt many rocks now designated simply as gneiss can be demonstrated to be secondarily foliated igneous granites, or granite-gneisses.[1]

In regions which have not been disturbed sufficiently to obliterate original structural relations, or where the metamorphism is not too profound, the age of an igneous granite may be determined as intermediate between that of a rock of known age through which it breaks and another which may possibly overlie it and into which it does not penetrate. Cases of the latter sort imply a great time-break, because of

[1]In the opinion of the writer the word "gneiss" should be used purely as a structural term for those crystalline feldspathic rocks whose original character can not be positively determined. In cases where such a determination is possible a qualifying term may be advantageously prefixed to indicate the origin, as for instance, granite-gneiss syenite-gneiss, diorite-gneiss, gabbro-gneiss, etc., for those derived from igneous masses, and arkose-gneiss, conglomerate-gneiss, phyllite-gneiss, etc., for such as have been undoubtedly produced from sediments.

the erosion required to expose a deep-seated or plutonic rock. In some instances granite bosses may seem to protrude through other rocks when they are in reality older than these, and are merely surrounded by them. The proofs of subsequent origin of an intrusive mass may be summarized as follows:

Exomorphic: Intrusion of the adjoining mass by dikes; brecciated contacts; inclusions of fragments torn from the adjoining walls; contact metamorphism of the adjoining rocks by hardening, recrystallization, and the development of new minerals.

Endomorphic: A change in the character of the intruding rock toward the contact; development of compact or porphyritic structure at the margin; development of spherulitic or micropegmatitic structures as a result of rapid cooling.

A few instances of the intrusion of igneous granites at various Paleozoic and pre-Paleozoic horizons may be cited. Ells describes intrusive granites in the eastern townships which have produced characteristic contact zones, accompanied by radiating dikes and apophyses.[1] Bailey mentions large granite masses as intrusive into the Devonian slates near the head of Miramichi Bay on the Gaspe Peninsula.[2] Faribault gives an account of many intrusive granites with contact zones and apophyses in the gold-bearing slates of Nova Scotia;[3] while other reports of the geological survey of Canada are filled with references to similar occurrences in the crystalline areas of Newfoundland, Cape Breton, and New Brunswick.

Throughout New England, and in the extension of the crystalline belt as far south as Alabama, eruptive granites of all kinds and ages seem to be no less abundant than in Canada.[4]

Professor Shaler has described the granite of Mount Desert and the adjoining islands on the coast of Maine as intrusive into the hard sedimentary slates of unknown age. These rocks show very characteristic and unmistakable eruptive contacts.[5] The same author has also recently described the granite of Cape Ann, Mass., whose age, while undetermined by any sedimentary bed, is probably younger than that of the diorite which accompanies it.[6]

Wadsworth has described the granites of Cape Ann and of Quincy, Mass.,[7] and has shown that the latter is younger than the Cambrian (Paradoxides) slates with which it is in contact.[8]

---

[1] Annual Report of the Geological Survey of Canada, for 1886, J, p. —.

[2] Ibid., N, p. 16.

[3] Ibid., P, p. 147.

[4] A rather full enumeration of the massive granites of Eastern United States, especially those which are either quarried or available for building or ornamental purposes, will be found in Vol. X of the reports of the Tenth Census, and in Mr. G. P. Merrill's handbooks for the U. S. National Museum and in his recent work on building stones.

[5] Seventh Annual Report of the Director of the U. S. Geological Survey, pp. 1035, 1052.

[6] Ninth Annual Report of the Director of the U. S. Geological Survey, pp 605-610.

[7] Proceedings of the Boston Society of Natural History, vol. 19, p. 309, Feb., 1878.

[8] Ibid., vol. 21, p. 274, Oct., 1881.

In New Hampshire, and especially in the White Mountain region, igneous granites are very abundant. Although no sedimentary rocks whose age is definitely known allow of the positive determination of the age of these granites, their relative ages can be made out by a study of their well-exposed contacts. Hawes, in his study of the beautiful tourmaline contact zones between the Albany granite and argillitic and mica-andalusite schist of Mount Willard, has shown that this rock is not only younger than the adjoining schists but also younger than the Concord and Conway granites with which it is associated.[1]

Pirsson has recently described a typical contact zone around a granite mass of Canonicut Island, Rhode Island, which is developed in shales of Carboniferous age, thus fixing the time of eruption of this granite as contemporaneous with the Appalachian upheaval.[2]

The other New England States doubtless contain good examples of this kind, but they have not as yet been sufficiently studied to show their geological significance. In the Middle Atlantic States, plutonic rocks of granitoid structure, like those of the Adirondacks, the "Cortlandt Series" on the Hudson, and others in New Jersey and southeastern Pennsylvania, abound, although within these districts truly igneous granites have not as yet received much attention from petrographers. Within the crystalline belt in Maryland granitic rocks have been studied with some care, and this joint paper is intended to embody the principal results thus far obtained. South of Maryland, while we know eruptive granites continue to be abundant, little has been positively learned in regard to them. Rocks very similar in character to the Woodstock granite of Maryland are extensively quarried in the vicinity of Richmond, while a coarser-grained granite is mentioned by W. B. Rogers as occurring near Petersburg.[3] Both Emmons[4] and Lieber[5] describe igneous granitic rock as abundant in the Carolinas. The writer has had opportunity of examining the contacts of the granite masses near Salisbury and Greensboro, N. C., and has found them to be those of a typical intrusive rock. The axis of the Blue Ridge south of the Potomac is largely composed of granitic rocks, more or less foliated by pressure, but their exact significance and relationship has not as yet been made out.

While the determination of the igneous character of plutonic masses which have remained unaffected by intense dynamic action since their solidification is attended with comparatively little difficulty, the demonstration of such an origin in greatly disturbed and intensely metamorphosed districts is a very different matter. The criteria set forth in the previous section for determining the igneous origin of rock may be used so long as they can be recognized, but in intensely folded districts the

---

[1] Am. Jour. Sci., 3d ser., Vol. XXI, pp. 21-32, 1881.
[2] Am. Jour. Sci., 3d ser., Vol. XLVI, pp. 363-378, Nov., 1893.
[3] Geology of the Virginias; reprint of annual report, etc., p. 71, 1884.
[4] Geology of the midland counties, North Carolina, p. —.
[5] Annual reports on the survey of South Carolina.

ordinary laws of stratigraphy, as Van Hise and Sederholm have pointed out, are not applicable. In such cases the classification of the rocks, the establishment, when possible, of their original character, and the distinction between their primary and secondary components and structures must rest wholly on petrographic data. In almost all cases the absolute determination of the age of such inclusive masses is out of the question. The best that we can hope to accomplish is to discover their relative ages; and this may be done, if at all, first, by a careful study of their contacts, and secondly, by the relative amounts of dynamic metamorphism which they have suffered. Thoroughly satisfactory results in highly disturbed districts where the relationships are very complex can be obtained only by a very detailed mapping, aided by elaborate laboratory investigation, and even then can be hoped for only when the natural exposures are so numerous and good as not to necessitate too much hypothesis in regard to the structure of intervening areas.

We may often hope to establish some definite time or times of especial dynamic action, so that we may be able to locate a given igneous intrusion as either anterior or posterior to it. In applying this test, however, we must remember that the same mass may be differently foliated in different parts, because of the unequal action of the pressure and its production of zones of unequal shearing.

If we carefully examine and compare those granites occurring in the crystalline portion of Maryland whose intrusive character is open to no reasonable doubt we find considerable contrast in the amount of foliation which has been secondarily produced in them. So, for instance, the granites of Ellicott City, Woodstock, Guilford, and on the lower portions of Accotink Creek, in Virginia, show little or no pressure effects. The masses near Sykesville, Texas, Rowlandsville on the Susquehanna, and the Murdoch Mill area west of Washington are slightly foliated, but not sufficiently so to disguise any of their essential features. These least-altered granites are the ones which have been especially studied by Dr. Keyes. In the Port Deposit region, in the Broad Branch granite area west of Washington, at the Relay, and in the augen-gneiss on the east side of the Texas granite area a secondary foliation has been produced by a completely new arrangement of the constituents. In the Piney Run type, on the other hand, which has already been described as occupying a large district south of Laurel and on the Potomac, extreme foliation has obliterated most of the granitic features, and it is only because of the abundance of indistinct masses resembling inclusions which are scattered through it that we assume for this rock an igneous origin.

With a view of securing all the light which their chemical composition could throw upon the origin of these doubtful gneissoid rocks according to the principle suggested by Rosenbusch (ante, p. 663), three representative specimens were selected from along the Potomac section west of Washington, and were analyzed by Mr. W. F. Hillebrand, of the U. S. Geological Survey, whose results are given below. I (720) is the typical gneiss of the Washington region, with apparent inclusions, taken from the quarry of the Potomac Stone Company, 1 mile below the Chain Bridge. II (671) is a rather fine-grained, fissile, chloritic gneiss from Emery's store, northwest of Cabin John Bridge. III (304) is a fine-grained, hard gneiss obtained at the second lock at Great Falls.

	I.	II.	III.
SiO_2	67.22	63.43	78.28
TiO_2	.84	.91	.70
Al_2O_3	15.34	16.69	9.96
Fe_2O_3	2 78	3.36	1.85
FeO	3.41	3.87	1.78
MnO	.13	.09	.08
CaO	1.36	.80	1.68
SrO	Trace.	Trace	Trace.
BaO	.04	.03	.02
MgO	1.65	2.33	.95
K_2O	3.26	3.22	1.35
Na_2O	2.00	2.38	2.73
Li_2O	Trace.	Trace.	Trace.
H_2O below 110° C	.29	.23	.12
H_2O above 110° C	1.68	2.67	.83
P_2O_5	.14	.11	.11
Total	100.14	100.12	100.44

An examination of these analyses shows that, in spite of their decided gneissoid structure, the first two are essentially basic granites in composition, not materially differing in this respect from the granites whose igneous character is well established. The third analysis, on the other hand, has no relation to any known igneous type, but agrees quite closely with certain siliceous sediments; so that, as far as the chemical evidence can be relied upon, we may safely regard this rock as of sedimentary origin. It is typical of all the highly siliceous rocks which form the barrier at the Great Falls, and its microscopical character is in accord with the evidence furnished by its chemical composition.

GRADATION OF MARYLAND GRANITES INTO OTHER FACIES.

The recent development of ideas relative to the gradual chemical differentiation of an igneous magma not only makes intelligible the intimate association of different but related rock types, which is so frequently encountered in nature, but leads us to expect such an association as a result of igneous origin. In all great districts of eruptive rocks, gradual transition of the prevailing type into others which differ from it both mineralogically and structurally is found to be the rule. It is therefore a matter of some importance to consider what chemical and structural facies are associated with those granites in the crystalline areas of Maryland which we have in the foregoing sections come to regard as of igneous origin. Structural differentiations which are to be accounted for by local variation in the physical conditions attendant upon solidification are not uncommon in all the areas under consideration. More or less abrupt change in the coarseness of grain is the most prominent of these, while in other cases, as for instance in the Ellicott City and Texas granite areas, a pronounced porphyritic structure is locally developed.

Gradation into a facies which presents chemical and mineralogical differences from the prevailing type is not to be accounted for by physical conditions at the time of solidification, but rather by chemical action in progress within the magma before solidification. In the northern portion of the Maryland crystalline belt, there is an intimate association of widely divergent and thoroughly distinct types of plutonic rock. Gradual passages from one of these to the other, at least as far as the granites are concerned, are comparatively rare. This fact indicates that the chemical differentiation had progressed very far before the eruptions took place, or that the material was derived from entirely distinct sources.

In the southern part of this belt, however, gradual passage from one rock type to another through all intermediate stages comes to be the rule. This is to be best seen south of Laurel, and is well marked in the igneous areas of the Laurel, Frederick, and West Washington atlas sheets of the U. S. Geological Survey. In the large granite area extending from Triadelphia southward to Brookville, in Montgomery County, the rock grades from a dark basic granite resembling a diorite to one which is very light colored and acid. In the Murdoch Mill granite area, west of Washington, gradual passages into a dioritic facies are frequent, while the same thing takes place with the development of still more basic varieties in the granite area which extends southward from Falls Church, in Fairfax County, Va. The most striking example of gradual passage from one igneous rock type to another is however to be found in the wide belt which crosses the Potomac River at Cabin John Bridge. This originates near the southern portion of the Frederick sheet, above Bethesda Park, as a normal gabbro similar to that occurring near Baltimore, and as it passes southward, it gradually becomes more acid, developing hornblende in the place of pyroxene, and thus merging into a diorite. Still farther south the diorite becomes biotitic, its feldspar more acid, while a little quartz commences to show itself. After the passage of the river the rock becomes a hornblende-granite, and without any break in the continuity of the mass, is developed along Pimmit Run as a typical granite.

To furnish a general idea of the chemical range of the plutonic rocks which have thus far been particularly studied and analyzed within the crystalline belt in Maryland, the following table of analyses is given, arranged in order of decreasing acidity:

Table of chemical analyses of the ancient igneous rocks of Maryland.

Name.	SiO_2.	TiO_2.	Al_2O_3.	Cr_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	Na_2O.	K_2O.	H_2O.	H_2O.	P_2O_5.	Total.	Analyst.	Group.
1. White granite, Brookville, Montgomery County, Md., (619 B).	74.87	.05	14.27	....	....	.51	....	.48	.16	3.06	5.36	.26	.66	.21	99.89	Hillebrand..	
2. Binary granite, Guilford, Howard County, Md.[1]	72.57	......	15.11	....	.59	1.02	....	1.65	.30	3.92	4.33	......	.47	....	99.96	.....do	
3. Biotite granite, gneiss, Port Deposit, Cecil County, Md.[2]	......	......	......	....	......	......	....	......	......	......	......	......	......	....	....	Bromwell...	
4. Biotite granite, Woodstock, Baltimore County, Md.[1]	71.79	......	15.00	....	.77	1.12	....	2.50	.51	3.09	4.75	......	.64	....	100.17	Hillebrand..	
5. Biotite granite, Sykesville.[1]	71.45	......	14.36	....	2.07	2.78	....	1.58	1.17	1.95	3.28	......	1.30	....	99.94	.....do	Granitic group.
6. Biotite granite, Dorsey Run Cut, Howard County, Md.[1]	70.45	......	15.98	....	.75	1.84	....	2.60	.77	3.83	3.59	......	.45	....	100.26	.....do	
7. Biotite granite-gneiss, Broad Branch Quarry, District of Columbia.[3]	69.33	......	14.33	....	....	3.60	....	3.21	2.44	2.70	2.67	......	1.22	.10	....	....	
8. Biotite granite, Rowlandsville Cecil County, Md.[4]	66.68	.50	14.93	(BaO).08	1.58	3.32	.10	4.89	2.19	2.65	2.05	.16	1.09	.10	100.32	Hillebrand..	
9. Granite (samples), Dorsey Run Cut, Howard County, Md.[1]	62.91	......	19.13	....	.98	3.20	....	4.28	1.69	3.94	3.38	......	.63	....	100.14	.....do	

10. Biotite diorite Georgetown, D. C. (317 B).	56.41	.83	15.19	.05	1.60	6.24	.11	6.77	7.18	2.21	1.34	.09	1.54	.05	100.05	.... do	Dioritic group.[5]
11. Biotite diorite, Triadelphia, Montgomery County, Md. (617 B).	55.97	1.11	15.60	.04	1.21	6.28	.08	7.31	6.83	2.23	1.25	.18	1.85	.16	100.10	.....do	
12. Gabbro, Mount Hope, Baltimore County, Md. (56 A).[6]	44.10	......	24.26	....	7.89	6.53	....	11.90	3.89	1.66	.24	......	.60	....	101.67	McKay	Gabbro group.[10]
13. Coarse diorite (gabbro-diorite), Ilchester, Howard County, Md. (333 A).[7]	43.42	1.25	22.37	....	.81	9.25	.06	13.34	5.75	1.24	1.13	.09	1.54	.10	100.35	Hillebrand..	
14. Hypersthene-gabbro, Windsor Road Bridge, Baltimore County, Md. (85 A).[8]	45.35	......	16.11	....	3.42	3.50	....	18.04	12.32		Difference.				100.00	Bayley......	
15. Hypersthene-gabbro, Wetheredville, Baltimore County, Md. (170 A).[9]	44.76	.13	18.82	.08	2.19	4.73	.15	14.58	11.32	.89	.11	.17	2.36	....	100.29	Hillebrand..	

[1] See C. R. Keyes.
[2] The very foliated biotite granite-gneiss so largely quarried for building stone. Its feldspar is mostly orthoclase. (See G. P. Grimsley, Cincin. Journ. Nat. Hist.)
[3] Resembles in appearance the Port Deposit rock No. 3..
[4] This rock is rather richer in biotite, and hence more basic than the prevailing type. Its feldspar is changed to epidote and is mostly oligoclase. (See G. P. Grimsley, Cincin. Journ. Nat. Hist.)
[5] Normal diorites of intermediate composition containing a little quartz and considerable biotite, besides their green hornblende and plagioclase.
[6] Contains somewhat more feldspar and diallage and less hypersthene than the type of this rock. (See Bull. U. S. Geol. Survey No. 28.)
[7] A coarse anorthite-hornblende rock; probably an altered gabbro.
[8] Poorer in feldspar and richer in hypersthene than No. 12. (See Bull. U. S. Geol. Survey No. 28.)
[9] Very like last; rich in both diallage and hypersthene. These two rocks are good types of the Baltimore hypersthene-gabbro.
[10] A type as low in silica as some peridotites, but high in alumina and therefore rich in a basic feldspar (bytownite).

Table of chemical analyses of the ancient igneous rocks of Maryland—Continued.

Name.	SiO_2.	TiO_2.	Al_2O_3.	Cr_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	Na_2O.	K_2O.	H_2O.	H_2O.	P_2O_5.	Total.	Analyst.	Group.
16. Olivine-gabbro, Orange Grove, Baltimore County, Md. (69 A).[1]	48.91	.37	8.81	.15	1.04	9.52	.16	14.69	15.19	.64	.10	.07	.52	....	100.17	Hillebrand..	Olivine-gabbro group.
17. Feldspathic lherzolite, Sudbrook Park, Baltimore County, Md. (54 A).[2]	41.00	......	7.58	....	5.99	4.63	....	10.08	23.59	.52	......	......	4.73	(CO_2) 3.62	101 74	McKay.....	
18. Websterite, Hebbville, Baltimore County, Md. (392 A).	53 98	.15	1.32	.53	1.41	3.90	.21	15.47	22.59	......	......	......	.83	....	100.39	Chatard.....	Websterite group.[3]
19. Websterite, Hebbville, Baltimore County, Md.	52.55	.14	2.71	.44	1.27	4.90	.24	16.52	20.39	.07	......	......	1.09	....	100.52	.....do	
20. Websterite, Johnny Cake road, Baltimore County, Md. (386 A)	50.80	......	3.40	.32	1.39	8.11	.17	12.31	22.77	......	......	......	.52	(Cl.) .24	100.03	Whitfield...	
21. Porphyritic lherzolite, Johnny Cake road, Baltimore County, Md. (174 A).[4]	43.87	.12	1.64	.44	8.96	2.60	.19	6.29	27.32	.50	......	......	8.72	....	100.63	Chatard	Ultrabasic group.
22. Cortlandtite, Ilchester, Howard County, Md. (317 A).[5]	39.20	.52	4.60	.41	3.45	6.15	.20 (NiO) .30	3.23 3.	31.65	.42	.14	.50	9.38	....	100.15	Hillebrand..	

[1] Rock like the Mount Hope hypersthene-gabbro, but it contains some fresh olivine with reactionary rims where it is in contact with feldspar.
[2] Rock considerably serpentinized and the basic feldspar (anorthite) largely changed to carbonates. (See Bull. U. S. Geol. Survey No. 28.)
[3] Group of rocks high in silica but very low in alumina and alkalies. Composed almost entirely of diallage and bronzite or hypersthene without feldspar. These rocks alter mostly to asbestos or steatite. (See Am. Geologist, July, 1890.)
[4] Rock largely serpentinized.
[5] Rock with large poikilitic hornblendes which are extensively changed to talc.

While this wide range of petrographic types can not be positively shown to have originated from a single magma, their relationships in the field are so intimate and the instances of the gradual passage from one to the other are so common, that this seems not to be an improbable hypothesis.

ORIGIN OF THE MARYLAND PEGMATITES.

Another important group of granitic rocks which is largely developed in Maryland, as it is in all other portions of the great Appalachian crystalline belt, embraces the very coarse-grained aggregates of quartz and feldspar, with more or less mica, variously known as pegmatites, giant-granites, or granitic veinstones.[1] These rocks are not considered by Dr. Keyes, since they form a group essentially distinct from the larger igneous masses which he especially studied. On the other hand, they are among the youngest of the products of granitic intrusion, and hence show little or no effect of dynamic metamorphism.

This group of very coarse-grained granites, so universally found in very crystalline regions, has always been an object of especial scientific interest. These rocks are always accompanied by an unusual number of rare and well-crystallized minerals, while the large scale upon which their essential constituents are developed also makes them of economic importance.

Pegmatites are known to be abundant all the way from Newfoundland to Alabama, although they have been for the most part explored and studied in America as localities for minerals. Many of the districts in eastern United States which have become mineralogically famous are great pegmatite dikes. It is only necessary to suggest the names of Stoneham, Hebron, and Auburn in Maine; of Grafton, Acworth, and Groton in New Hampshire; of Huntington, Goshen, and Chesterfield in Massachusetts; of Branchville and Haddam in Connecticut; of Leipersville in Pennsylvania; of Amelia in Virginia, and of the well-known mica mines in western North Carolina, to show that in eastern United States pegmatites are no less rich in rare minerals than are similar dikes at Pikes Peak in Colorado or at Harneys Peak in the Black Hills. An examination of the best-known foreign mineral localities would show an equal preponderance of pegmatite dikes, as, for instance, the granitic regions of Elba, of Switzerland, of the Pyrenees, of the Mourne Mountains in Ireland, and of Silesia, Scandinavia, and the Urals.

The economic products of these coarse-grained granitic dikes are mica, feldspar (largely used in porcelain manufacture), quartz, and a

[1] The term "pegmatite" was first suggested in Haüy in 1822 for those regular intergrowths of quartz and feldspar which are now designated "graphic granite." In 1849 Delesse extended its use over all the very coarse granites. He was followed by Naumann in his Lehrbuch der Geognosie, and since that time the word pegmatite has been generally adopted for this entire group of coarse-grained granitic rocks, and even for the corresponding equivalents of other plutonic masses, as for instance syenite-pegmatite, diorite-pegmatite, gabbro-pegmatite, etc.

large number of minerals containing the rarer earths, which are almost exclusively found in this association.

The pegmatites of Maryland are not noticeably rich in unusual minerals, nor have they become of any economic importance. Their abundance, however, and their relations to the larger masses of intrusive granite render them well worthy of study, especially from the point of view of their origin.

There is hardly any group of rocks which enters largely into the composition of the earth's crust whose origin has been the subject of so much study and discussion as the pegmatites. Observation in many widely separated districts has led to the suggestion of many very diverse theories. Between those who hold that they are simple igneous injections, on the one hand, and those who maintain that they are the result of a leaching process through the agency of the ordinary percolating surface waters, on the other hand, almost every imaginable hypothesis has been advanced.[1]

Charpentier, who was one of the first to study these rocks, regarded them merely as contemporaneous injections of the residual granite magma, and hence, as the final step in the process of granitic consolidation.[2] He was followed in this idea by De la Beche, by Bronn, Fournet, Durocher, and Angelot. Naumann is also inclined to think this the most probable theory and calls them "after-births" of the granite.[3]

Élie de Beaumont, in his famous essay "Sur les Émanations volcaniques et métallifères,"[4] while accepting in the main the igneous and intrusive origin of pegmatites, introduced an important addition in assuming water and other mineralizing agents as necessary factors in their formation. He correlated the pegmatites with the other phenomena so common in the peripheral regions of granitic districts, or, as he called it, "granite aura" (the penumbra of Von Humboldt). De Beaumont, while assuming granitic emanations as necessary for the crystallization of the coarse-grained granites, is careful to distinguish between them and the banded concretionary veins formed by substances dissolved in circulating heated waters.

Scheerer, in a paper published about the same time as that of De Beaumont, attributed a still more important rôle to water in the formation of pegmatites, holding what Hunt has designated as the theory of "granitic juice", a highly heated aqueous solution of mineral substances impregnating the congealing mass and oozing out under pressure into the surrounding rocks.[5]

The intrusive theory of the origin of pegmatite, with the aid of water and other mineralizers as important factors, has been recently advocated

[1] Good historical summaries of the development of opinion with regard to the origin of pegmatites are given by Naumann, Hunt, Huntington, and especially by Brögger, so that no exhaustive résumé of the preexisting literature on this subject is here necessary.

[2] Essai sur le Const. géogn. des Pyr., p. 158, 1823.

[3] Lehrbuch der Geognosie, 2d. ed., vol. 2, p. 232, 1858.

[4] Bull. Soc. Géol. Fr., (2) IV., p. 12.

[5] Bull. Soc. Géol. Fr., (2) IV, p. 468, 1847. F. Hunt: Chem. and Geol. Essays, p. 189, 1875.

by J. Lehmann[1] and by Brögger,[2] and may be regarded as the most acceptable for all those masses which are in intimate association with larger plutonic intrusions. These two authors differ in that the former assumes a viscous or colloid state of the material at the time of its injection into the fissures surrounding the granite mass, and thinks that no high temperature is necessary; while the latter regards the pegmatite dikes as formed under more normal igneous conditions, although allowing the importance of mineralizing action. A similar aqueo-igneous theory for the origin of pegmatite has recently been advanced in this country by W. O. Crosby.[3]

All those who have held either the purely igneous or the aqueo-igneous (pneumatolytic) theory of the origin of pegmatite have, of course, conceived this rock to be contemporaneous with the granite masses with which it is associated. Others have also maintained this contemporaneous character while attributing to water a much more important rôle. Thus, Keilhau, Hausmann, and Daubrée[4] thought of the pegmatite veins of southern Norway as mainly aqueous deposits, but regarded them as genetically connected with granitic intrusions. Lossen, in his conception of what he designated "Primärtrümmer," seems to have had an analogous idea.[5] Reyer regards them as excretions of the solidifying magma, representing the last stage of solidification where water was largely active (Secretgänge, Exsudate).[6]

Other geologists have maintained the purely aqueous origin of pegmatites as bodies altogether subsequent to and independent of any larger masses of intrusive granite. Among those who have held this view there has been, as in the other class, a considerable diversity of opinion as to the exact manner in which the result has been accomplished, but all agree in regarding circulating waters as the efficient cause. Saussure was the first to advocate an origin of pegmatites in this manner. Vom Rath, in his description of the pegmatite veins of Elba, assumes that they were deposited by heated aqueous solutions ascending from below.[7] The prevailing theory, however, both in Germany and America, is that they have resulted from the leaching of the material from the surrounding rocks, and its gradual concentration or segregation in fissures. This theory, which may be called "the lateral secretion hypothesis," has long been a favorite one for both ore veins and pegmatites. It has been ably advocated in Germany by Hermann Credner[8] and Klockmann,[9]

[1] Ueber die Entstehung der altkrystallinischen Schiefergesteine, p. 24 et seq., 1884.

[2] Die Syenitpegmatitgänge der südnorwegischen Augit und Nephelinsyenite, I. Theil, pp. 215-225. Zeitschr. für Kryst., vol. 16, 1890.

[3] American Geologist, vol. 13, p. 215, March, 1894.

[4] Annales des Mines (4th ser.), vol. 4, pp. 199-282, 1843.

[5] Zeitschr. d. deutsch. geol. Gesell., vol. 27, p. 969, 1875.

[6] Theoretische Geologie, p. 101, 1888.

[7] Zeitschr. d. deutsch. geol. Gesell., vol. 22, p. 649. 1870.

[8] Ibid., vol. 27, p. 104, 1875.

[9] Ibid., vol. 34, p. —, 1882.

and in this country by Hunt,[1] Dana,[2] Huntington,[3] Kerr,[4] and many others.

The principal arguments upon which this hypothesis is based are (1) a direct dependence observed in some localities of the character of pegmatite upon the chemical composition of the rock in which it occurs; (2) a symmetrical arrangement of the constituents in lines more or less parallel to the walls of the vein; (3) the occurrence of pegmatite in isolated lenses or eyes, which in many metamorphic schists seem to be entirely disconnected from any possible source of injection; (4) a drusy character of the pegmatite veins; (5) association with and gradation into veins of pure quartz.

A few other theories of quite different nature from those mentioned above have also been advanced, but they hardly seem worthy of serious consideration. Thus Kalkowsky suggests that pegmatite might be formed through the melting of granulite material brought about by dynamic agencies;[5] and Goodchild has supposed that lenses of pegmatite might be due to local fusion through the relief of pressure in rock-masses which were potentially molten but kept in a solid state through pressure.[6]

Only by assuming that they have attempted to cover by a single explanation a number of similar rocks which are genetically distinct is it possible to account for so many competent observers having arrived at such diverse conclusions regarding the origin of pegmatites. It seems tolerably certain that there are some coarse-grained quartz-feldspar aggregates which have been formed by a gradual process of segregation. Daubrée's experiments have shown that water quite readily leaches out the alkaline silicates from rocks[7] and their subsequent deposition in preexisting fissures or cavities might produce pegmatitic aggregates. On the other hand it is equally certain that other masses which are mineralogically and chemically identical with these are to be accounted for by the injection of unsolidified granitic material. Investigators in different localities have encountered evidence pointing to one or the other of these modes of origin, and have attempted from this to formulate a general theory covering all pegmatites, without attempting to distinguish between them, or even allowing that this type of rock may have originated in more than one way. The writer's studies in Maryland have led him to believe that both segregation and intrusive pegmatites, quite similar in appearance, appear side by side, and he will here attempt to set forth the evidence upon which their distinction rests.

[1] Am. Jour. Sci, 3d ser., Vol. I, p. —, Feb., 1871.
[2] Manual of Geology, — ed., p. —.
[3] Geology of New Hampshire, vol. 2, p. 76, 1877.
[4] Proc. Am. Inst. Min. Eng., vol. 8, p. —, 1880.
[5] Zeitschr. d. deutsch. geol. Gesell., vol. 33, p. 629, 1881.
[6] Geological Magazine, Decade IV, vol. 1, p. 26, Jan., 1894.
[7] Géologie expérimentale, p. —

SEGREGATION PEGMATITES.

In a deeply eroded and greatly decomposed crystalline area, like the Piedmont Plateau in Maryland, no one can doubt that the immense amount of white vein-quartz (commonly called flint, which in many regions is the only rock which ever appears visible at the surface), represents the segregation of silica with which nature has healed the many wounds and ruptures caused by the profound orographic dislocations. In all greatly disturbed and metamorphosed areas we find the rents and fissures occupied by quartz veins of secondary origin, which are the scars indicating the convulsions through which the strata have passed in the process of mountain making. Where a favorable exposure lays bare the rock beneath such flint-covered soil we find the white vein-quartz seaming and penetrating the schists in all directions. It is sometimes in small and isolated eyes, representing only a minute opening between the strata. In some cases these eyes grow to larger lenticular masses, though these are still completely isolated from one another. In still other cases these lenticular masses become joined to veins, which may continue for considerable distances.

In such typical quartz veins we occasionally find radiating black tourmaline or small masses of flesh-colored feldspar. The occurrence of these is identical with that of the pure quartz veins, and there is no reason to assume that they have originated in any other way. In rarer instances the feldspar or tourmaline may increase in amount and have associated with them mica or other minerals. Such aggregates occur, like the quartz, in isolated lenticular eyes with the much crumpled and sheared gneisses, and it is difficult to imagine how they could have come into their position except by a gradual process of leaching and deposition through circulating water.

INTRUSIVE PEGMATITES.

While it is admitted that there are many coarse-grained feldspar aggregates of limited dimensions occurring within the Maryland gneisses, whose origin is the same as that of the widely distributed quartz veins which have resulted from the intense orographic disturbance of the strata, there are other pegmatites occurring in distinct dikes whose genetic relationship to the great masses of intrusive granite is beyond all doubt. There may indeed be cases where the assignment of a given occurrence to one or the other of these modes of origin is uncertain, but there are in Maryland a number of admirable exposures where the igneous origin of pegmatites and their intimate connection as an integral part of a granitic intrusion are so plain as to be open to no question. These show none of those features upon which arguments for an origin by lateral secretion are commonly based. They have no symmetrical banding parallel to their walls; they are sharply defined from the adjoining rocks, while their character is in no way related to the chemical composition of the material which incloses them. They are not especially rich in unusual minerals, and hence they differ but little in their bulk composition from the normal granites with which they are connected; though often of a very coarse grain, they sometimes show finer-grained portions, and not infrequently grade into rocks quite like those forming the main part of the mass from which they radiate. They also show positive evidence of igneous or intrusive origin in their relations to the rocks which they penetrate. They form branching dikes which often cut obliquely or at right angles across the foliation of the schist. They include fragments of various sizes and angular dimensions, torn from the adjoining walls and variously dis-

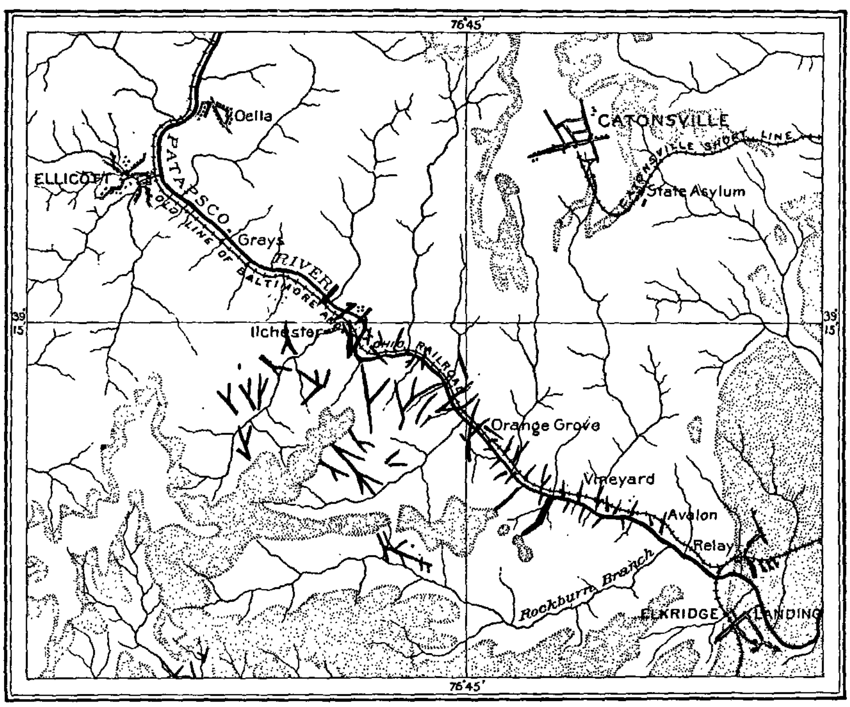
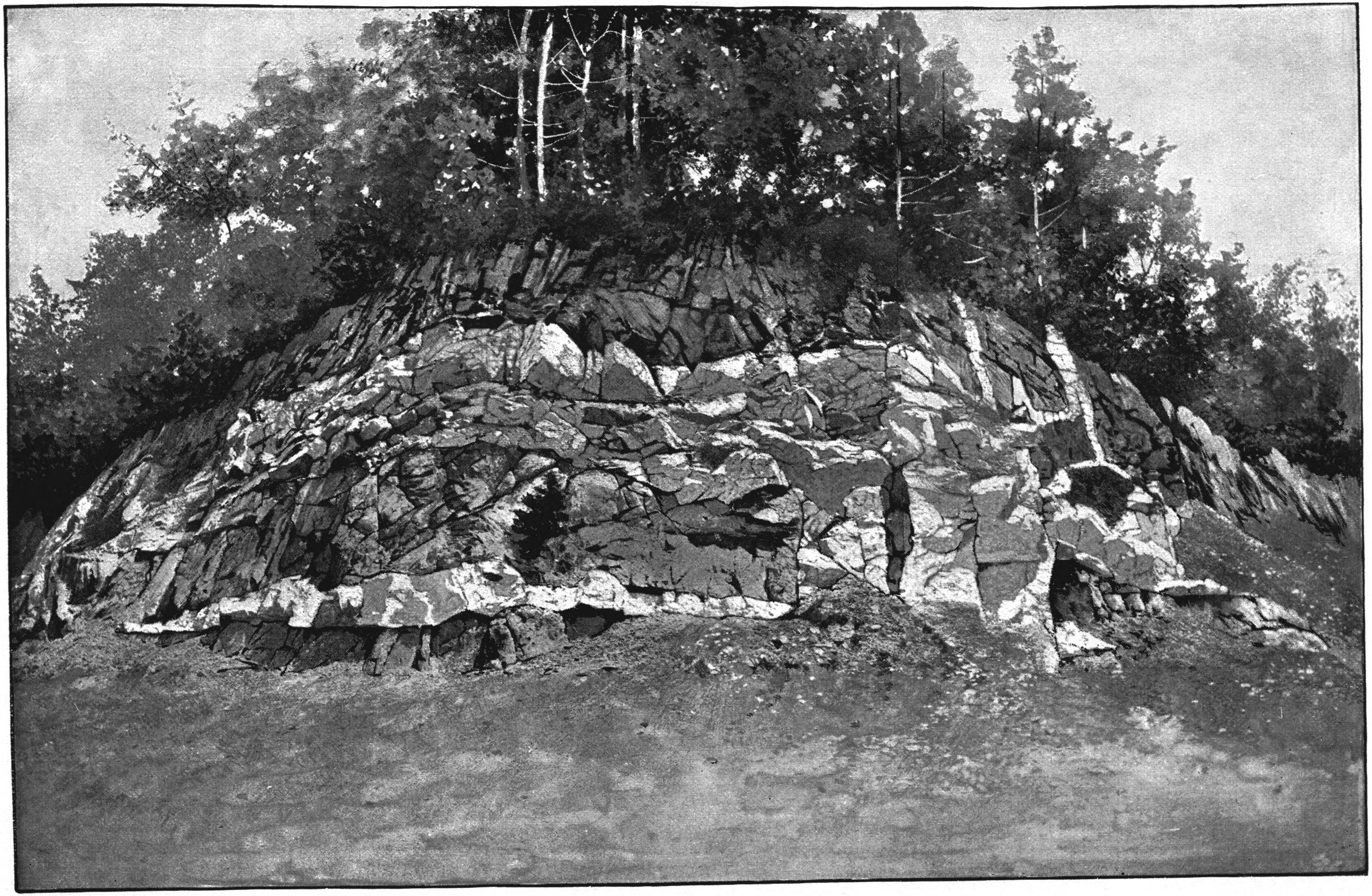


FIG. 21.—Map of Patapsco River, between Relay and Ellicott City, Md.

placed. They are intimately associated in their distribution with large areas of normal intrusive granites, becoming regularly less and less abundant as they recede from their boundaries. They cut indiscriminately, without any change of character, across rocks of the most diverse kind.

Two or three occurrences may be described as sufficient to establish the igneous origin of the Maryland pegmatite dikes of this category. The first of these is seen along the line of the Baltimore and Ohio Railroad, between the Relay and Ilchester, where the railroad cutting has yielded many favorable exposures. There is a small area of igne-



PANORAMA; PEGMATITE DIKES, ORANGE GROVE.

ous granite at the Relay, and another much larger one which extends from Ellicott City eastward as far as Orange Grove. As may be seen from the accompanying map, this granitic area lies for a considerable distance just north of the Patapsco River, and crosses it between Ilchester and Orange Grove. The deep gorge cut by the river therefore affords admirable exposures of the pegmatite masses, which occur both within and radiating outward from the main granite body.

The surrounding rocks are hornblendic gneisses, which have originated from the dynamic metamorphism and foliation of old gabbro masses. The granite itself is younger than the period of this foliation, as it shows little or no effects of pressure. One of the best examples of an instrusive pegmatite to be seen anywhere in the Piedmont Plateau is exposed in the wall of the railroad cutting just west of Orange Grove Station. The front view of this exposure is represented in Pl. XXVIII. A view looking eastward from its western end is given in Pl. XXIX, and a detail toward the eastern end in Pl. XXX. The hornblende-gneiss, containing occasional micaceous bands, has a cleavage-dip of 60° to 70° S. 35° W., and a strike N. 55° W. At one point a coarse-grained granitic mass 18 feet in width emerges from the ground, like the trunk of a huge tree, very nearly in the direction of the dip of the gneiss. From this, two lateral branches are given off on each side, the lower ones being in both cases the narrower. These cut at right angles to the foliation of the gneiss, and may be traced in a horizontal direction for a distance of 70 feet toward the east and 150 feet toward the west. The lower branches are not over 4 feet in width, and both of them inclose several fragments of the gneiss which have been torn off from the walls and embedded in the granite. The liquidity of this rock, as well as the pressure under which it was erupted, may be inferred from the minute—often microscopic—fissures into which it has penetrated. The lower arms exhibit the effect of more rapid solidification near the walls, where they are much finer grained than in their centers. The main trunk of granite, which is about 18 feet in width, gives off two other horizontal branches at a distance 13 feet above the lower ones. These upper branches are much wider, reaching a maximum width of 22 feet, and maintain their course for a long distance parallel to the lower branches. From them several smaller dikes of granite penetrate upward into the gneiss, either parallel or more or less oblique to its foliation. The main trunk exhibits all the phenomena displayed by the lower branches on even a larger scale. One great inclusion of gneiss is 14 feet in length and 2½ in breadth.

The rock composing these dikes is a muscovite-granite, essentially like the main mass of granite with which it is connected, except that it is more acid. It is composed of quartz, microcline, albite, muscovite, and occasional small crystals of red garnet. No biotite was observed.

East of Orange Grove the pegmatite dikes become less and less numerous as one passes from the granite boundary. A few small but very sharply defined intrusions of this character may be seen cutting obliquely across the foliation of the hornblende-gneiss near Vineyard, about half way between Orange Grove and Relay. Two of these are represented in Pls. XXXI and XXXII. In composition they are like the rocks at Orange Grove, though they have a somewhat finer grain. Their relation to the adjoining gneiss leaves little doubt of their truly eruptive character. At Ilchester Station, but on the north side of the river, between the railroad and carriage-road bridges, some pegmatite dikes of more than usual distinctness occur. They radiate in various directions and penetrate the dark-colored gneiss without reference to its foliation. In some of the larger of these, concentration of certain

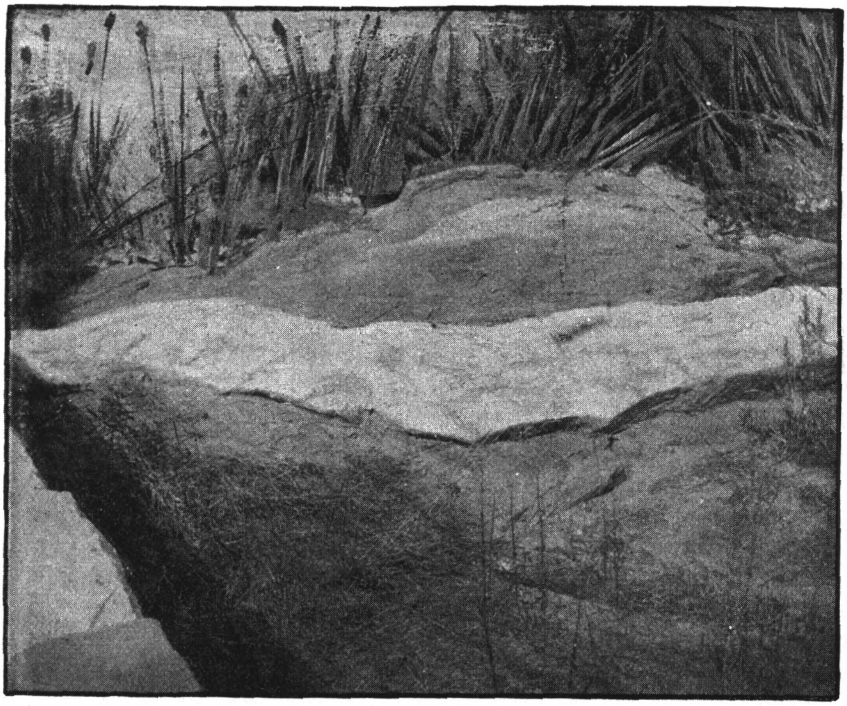
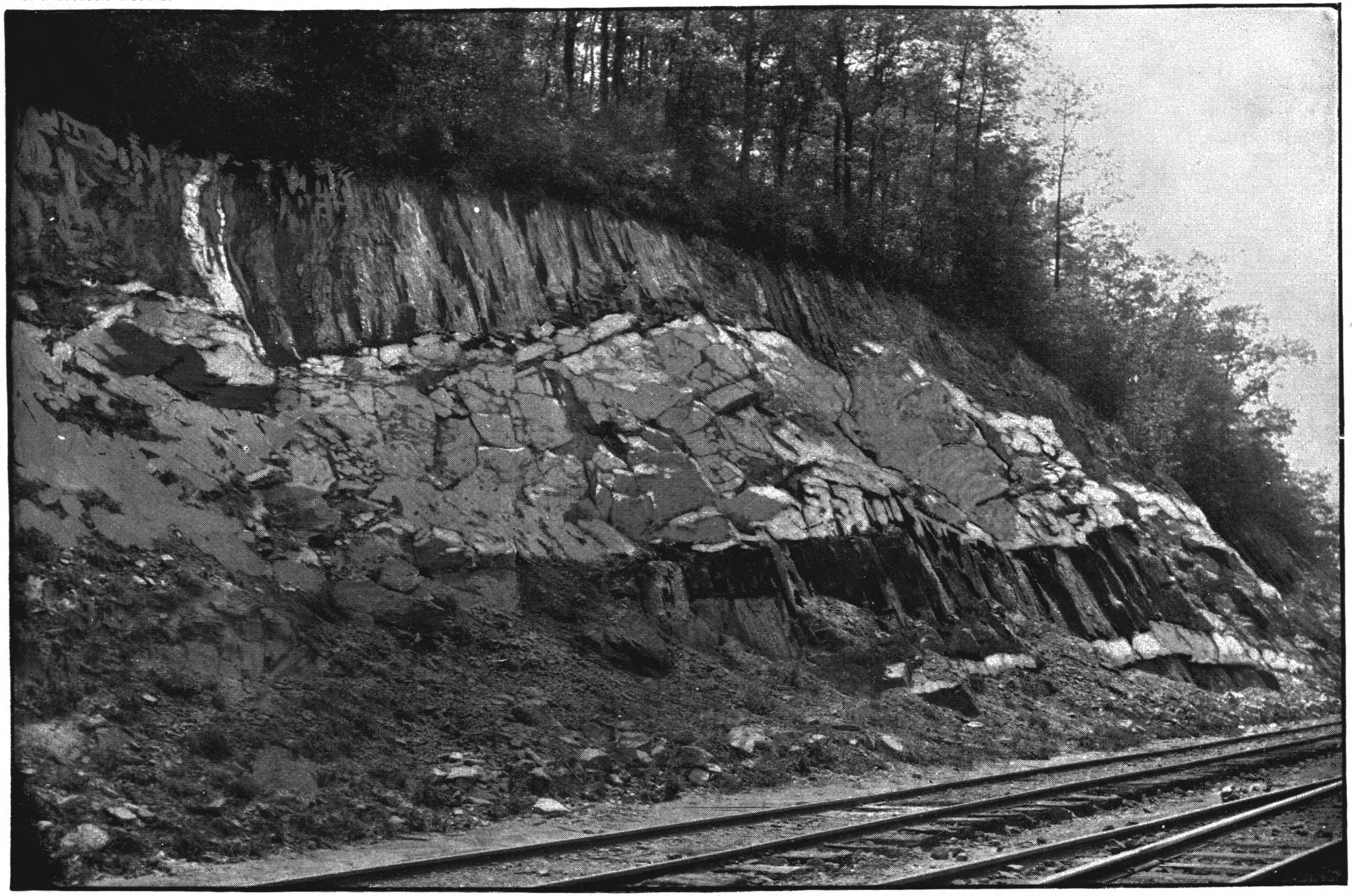


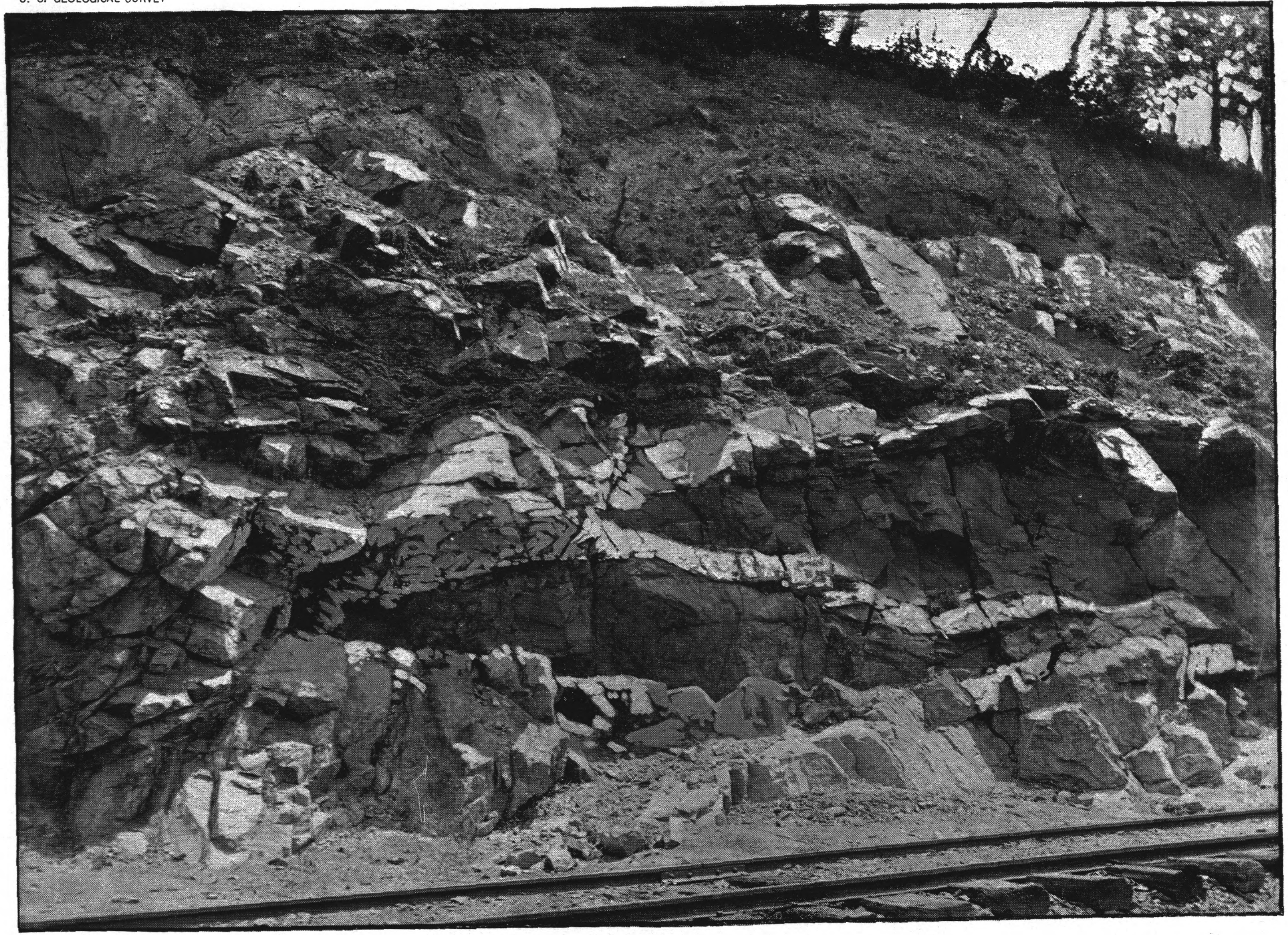
FIG. 22 —Pegmatite dike, Jones Falls, Baltimore, Md.

of the constituents in bands more or less parallel to the walls is observable. The appearance of these dikes is represented in Pls. XXXIII and XXXIV.

In the well-known quarries of gneiss on Jones Falls in Baltimore, pegmatite veins are very common. Some of these show evidence of having been formed by the process of segregation, while others seem to be intrusive. Here the most abundant pegmatite carries a jet-black mica in the place of muscovite, although muscovite-pegmatites also occur. There seems to be no relation between the character of the adjoining rock and the particular kind of pegmatite which occurs



PEGMATITE DIKES, ORANGE GROVE; VIEW FROM WEST END.



PEGMATITE DIKES, ORANGE GROVE; DETAIL AT EAST END.

within it. The intrusive character of the pegmatite in this vicinity is well shown by a dike of very acid material, composed of quartz, pink feldspar, and muscovite, which cuts obliquely across the dark hornblende-schists on the side of Jones Falls between Preston and Hoffman streets. The accompanying figure (22) of this dike is drawn from a photograph taken in 1884, though this exposure has been for some time buried beneath the improvements in this part of the city.

The entire lack of any connection between the intrusive pegmatites and the rocks in which they occur is nowhere better shown than along the Gunpowder River, below Loch Raven. Between Notch Cliff and Summerfield, on the Baltimore and Lehigh Railroad, great dikes of pegmatite occur in gneiss, which continue their course into and across the belt of crystalline limestone which forms the Mine Bank valley, without in any way changing their petrographical character. In a small quarry on the north bank of the river just east of Summerfield, a very distinct contact is shown between the limestone and the pegmatite which here overlies it. (See Pl. XXXV.)

The evidence that certain, at least, of the coarse-grained granites or pegmatites occurring in the crystalline rocks of the Piedmont Plateau near Baltimore are of eruptive origin may be summarized as follows:

1. They agree essentially in chemical and mineralogical composition with the granite masses whose igneous origin is well established, although they are in the main somewhat more acid than these.

2. Their size and abundance are directly proportional to their nearness to some eruptive granite mass. At many localities they can be seen to decrease steadily both in number and size as they recede from such a granitic boundary.

3. While they agree closely in composition with large masses of igneous granite, they are quite independent of the character of the rocks which surround them. It has been shown by Credner and conceded by Lehmann that in Saxony such a connection between the character of the pegmatite and that of the surrounding rock exists, but in the Baltimore region this is not the case, as appears from the many instances where the most acid pegmatites cut the basic gabbro and peridotite or where similar rocks continue their course from gneiss into limestone without essential change.

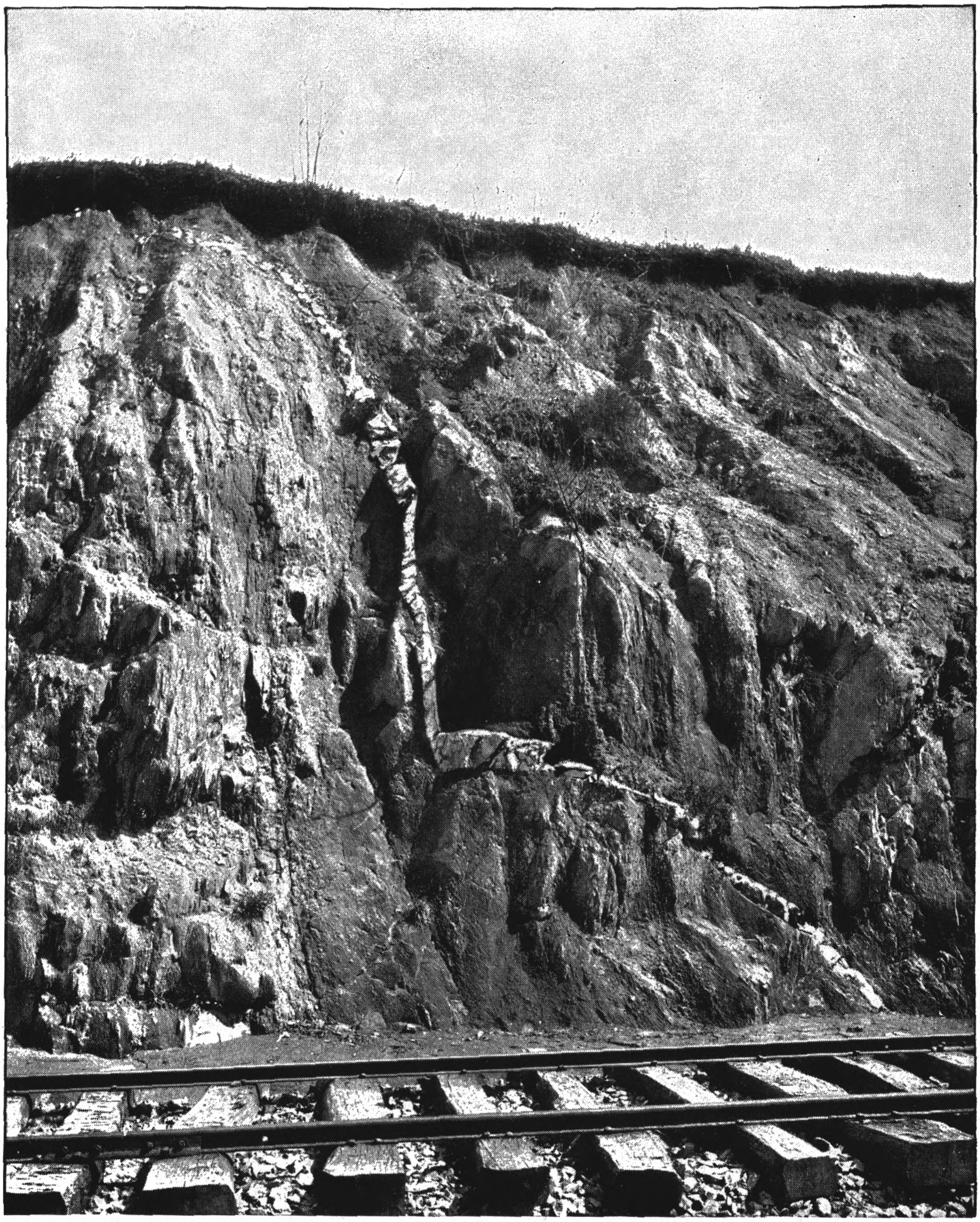
4. Those pegmatites which are interpreted as intrusive in the Baltimore region are not as a rule either drusy or symmetrically banded. They are frequently finer grained toward the edge of the dike than at the center, and their finest-grained varieties agree quite closely in appearance, composition, and structure with the normal igneous granite.

5. These pegmatite dikes show in their relations to the adjoining rock the strongest evidence of their intrusive character. They are often but by no means always, concordant with the foliation of the rocks in which they occur. When this is so, it is because they have followed the line of least resistance; but in many other cases these dikes branch in

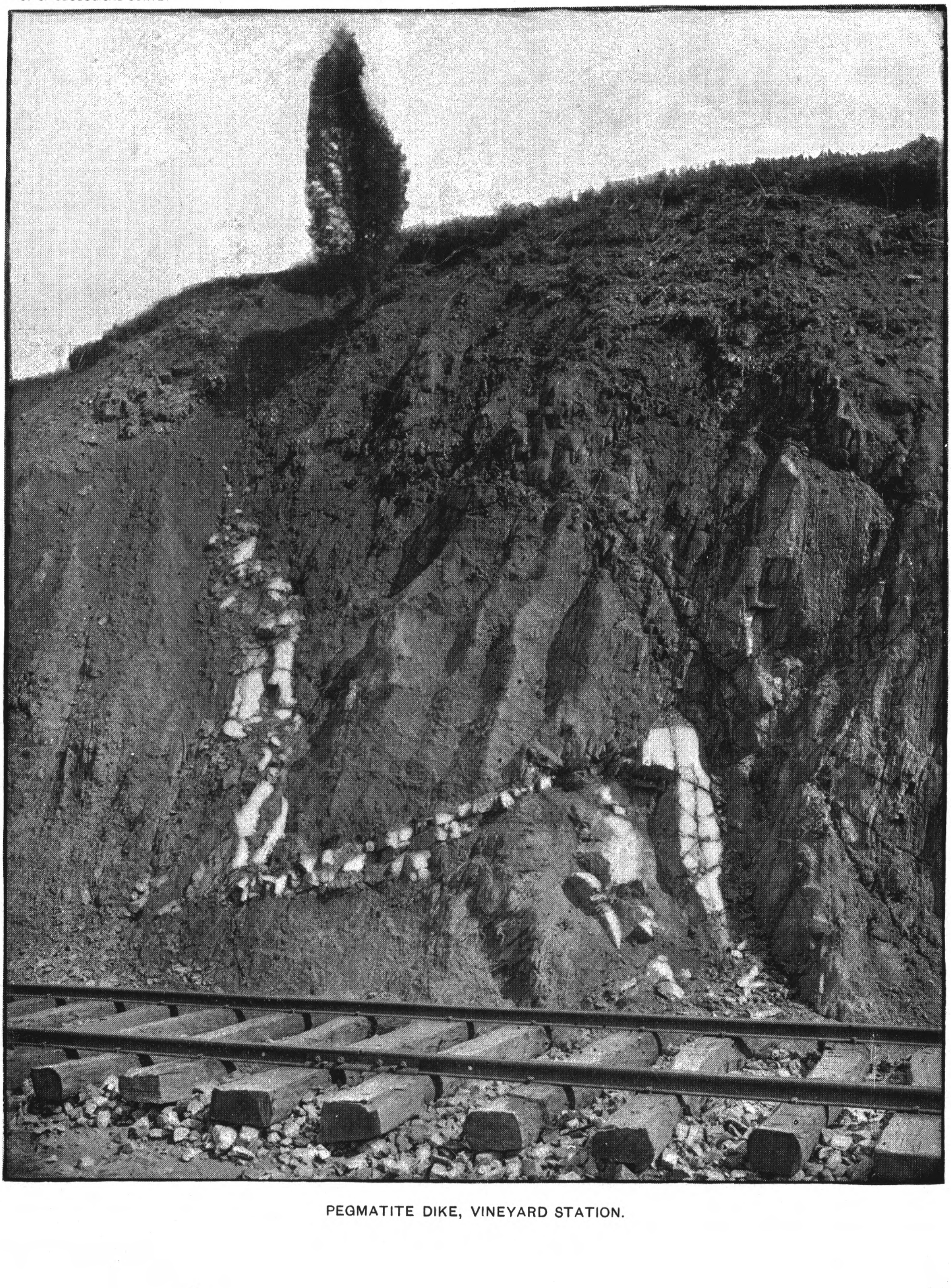
various directions, and cut at all angles across the foliation of the schists, as may be seen in several of the accompanying plates.

6. In spite of the essential identity in composition between the pegmatites and the normal granites, there are certain differences which indicate that the crystallization of the former was facilitated by a greater activity of mineralizing agencies. Unusual minerals, while not especially abundant in the Maryland pegmatites, occur often enough to point to somewhat different conditions of formation than those which prevail within the larger plutonic masses.

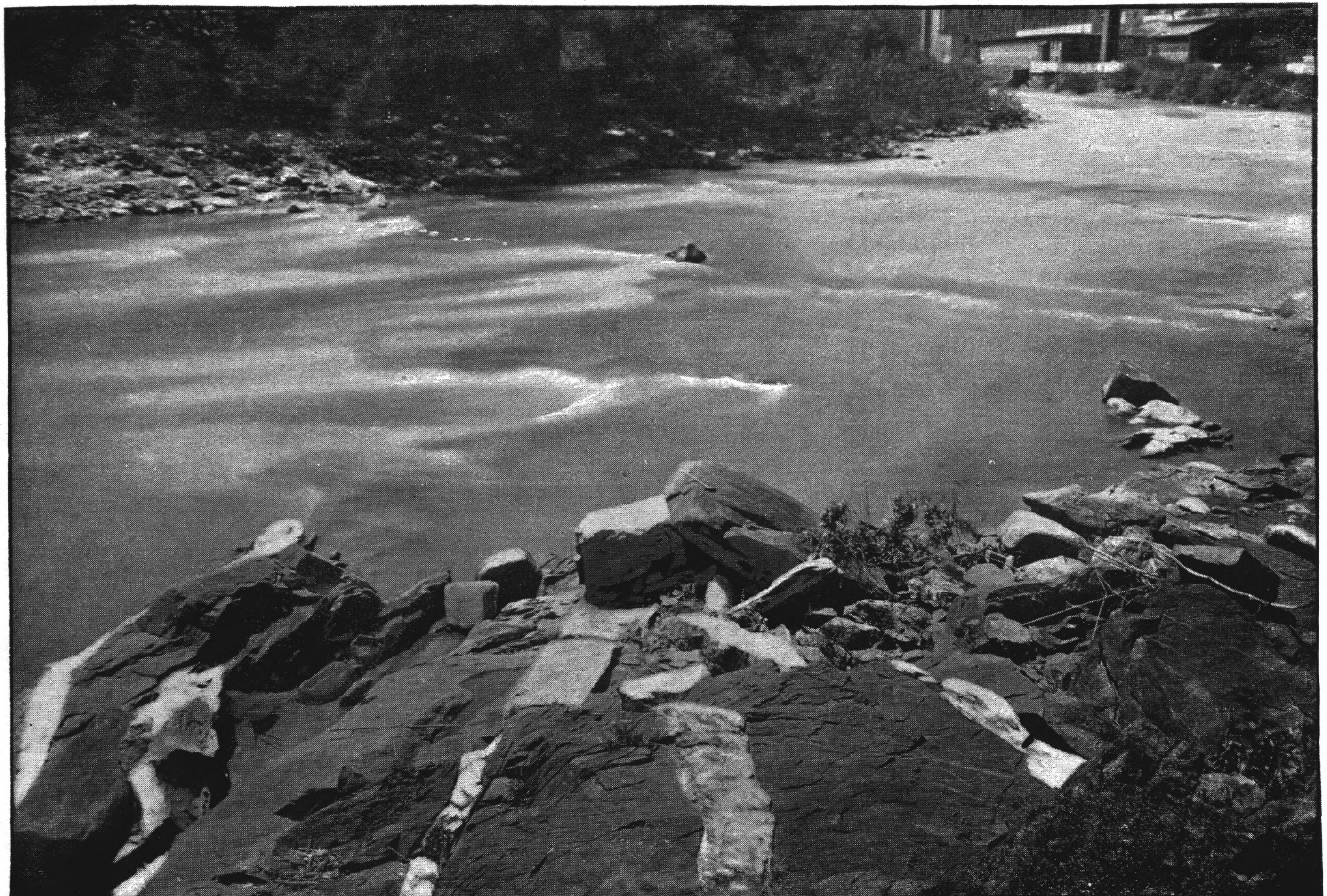
The writer's conception of the relation between these intrusive pegmaties and the granite with which they are associated does not materially differ from the conceptions of De Beaumont, Lehmann, and Brögger. As Lehmann and many others have distinctly pointed out, a gradually solidifying magma tends through the processes of crystallization to become more and more acid, and at the same time more and more liquid. The water and other mineralizing agents which all acid magmas contain become gradually excreted and concentrated in the residual portion, since they can not enter directly into the composition of the normal granite. We are accustomed to connect coarseness of crystallization in igneous rocks with slowness of solidification, and while this is doubtless a correct conception, it does not necessarily follow that very coarse-grained rocks are always produced in this way. If the facility of molecular motion be sufficiently increased and the conditions of crystal growth are thereby rendered more favorable through the presence of volatile substances, we may get coarse-grained mineral aggregates in a comparatively short period of time. The writer therefore interprets those pegmatites which by their mode of occurrence and association strongly indicate an igneous character as the products of the residual and therefore most acid portion of a granite magma highly charged with water and other mineralizing agents. Such a siliceous material, in a state intermediate between fusion and solution, has been injected into fissures and there crystallized into very coarse-grained aggregates, not necessarily through any great slowness of this process, but rather in virtue of the aid to crystallization afforded by the abundance of mineralizers present.



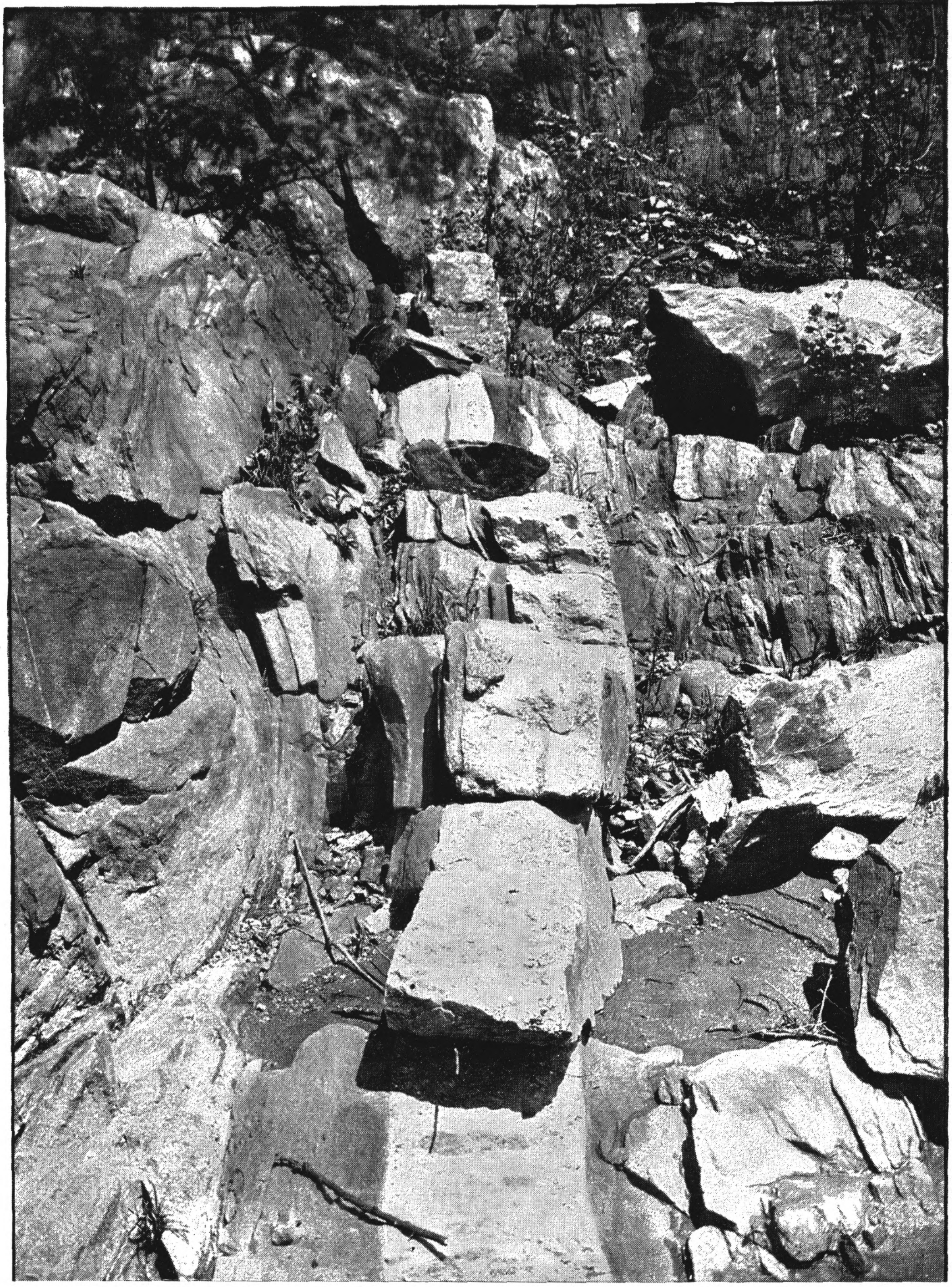
PEGMATITE DIKE, VINEYARD STATION.



PEGMATITE DIKE, VINEYARD STATION.



PEGMATITE DIKES, ILCHESTER STATION.



PEGMATITE DIKES, ILCHESTER STATION.

CONTACT OF LIMESTONE AND PEGMATITE, SUMMERFIELD.

ORIGIN AND RELATIONS OF CENTRAL MARYLAND GRANITES.

By Charles Rollin Keyes.

PREFATORY NOTE.

The accompanying contribution to a knowledge of Maryland petrography embodies the results of a study of the granitic rocks lying within the eastern Piedmont zone in the central portion of the State.

These rocks comprise light-colored and dark-colored granites, felsitic and fine-grained granitic dikes, pegmatites, and granitic gneisses. For reasons hereafter stated, the latter two kinds receive but passing mention here. The occurrences under consideration have occupied attention both in the field and in the laboratory. The evidence accumulating from this investigation has afforded abundant grounds for believing that—

(1) Certain granites are eruptive in nature.

(2) Certain of the gneisses are squeezed granites.

(3) Epidote occurs as a primary constituent of acid eruptives.

(4) Muscovite is an original component of some of the most acid granites.

This study of the Maryland granites was undertaken at the suggestion of Prof. George H. Williams, of the Johns Hopkins University, Baltimore, to whom sincere thanks are extended.[1] Professor Williams also generously allowed his field notes of the Baltimore region to be accessible at all times, besides freely giving counsel and advice which added zest and pleasure to the work. Thanks are also due Mr. W. J. McGee, until recently chief of the Potomac division of the U. S. Geological Survey, for aid and many kind attentions.

[1]Since this was written we have been called upon to mourn the untimely death of Professor Williams.

CHAPTER I.

INTRODUCTION.

PRELIMINARY REMARKS.

The crystalline rocks of Maryland have come into considerable prominence recently, partly on account of the variety of interesting rock types represented, partly by reason of the light thrown by them upon the intricate problem of regional metamorphism in eruptive masses. The interest awakened in the petrographical consideration of the region has been due in great measure to the researches of Prof. George H. Williams, whose investigations have extended over a period of some years.[1] The results of these observations, upon the basic and intermediate series especially, have been given from time to time in various papers, chief among which are, "The gabbros and associated hornblende rocks occurring in the neighborhood of Baltimore, Md.,"[2] and "The nonfeldspathic intrusive rocks of Maryland and the course of their alternation."[3]

Recently considerable additional information has accumulated, particularly in regard to the acid rocks of the State. The most essential features of this study are set forth here, the discussion being restricted to the massive occurrences. Some allusion, however, is made to the light-colored gneisses so intimately related to the granites of the region. The pegmatitic series has been but briefly mentioned at this time, for the reason that it will receive special elaboration in another place.

In an area which undoubtedly represents the denuded base of an old mountain range, it might be expected that regional metamorphism and molecular change had operated to a considerable degree; and such is found to be actually the case, though the subject has not been investigated to the extent that it might be, or probably will be in the near future. Indeed, this line of work in the Piedmont region of Maryland promises to be most fruitful in interesting results.

It bears directly upon what is, it may be, one of the most far-reaching generalizations of modern times—the conception of the perfect harmony existing between matter and its physical environment; an adjustment intensely sensitive, self-acting, ever changing. It is a relation ruling in the organic and inorganic worlds alike. In biology

[1] [See note at foot of p. 658.]
[2] Bull. U. S. Geol. Survey No. 28, Washington, 1886.
[3] American Geologist, Vol. VI, pp. 35–39, Minneapolis, 1886.

this idea has long had a most important bearing upon philosophical thought; and although of late the theories have been set aside to a great measure by a certain class of workers, the original propositions are gradually reclaiming attention with a far deeper meaning than they originally had. Especially is this so in the light of the recent deductions of certain of the purely physical sciences.

Independent of the ordinary physical changes of environment, the crust of the earth is sooner or later influenced by mountain-making movements and other forces resulting from the secular cooling of the globe. Alteration is thus ever going on in the rocks. Indeed, the whole mineralogical composition and structure of stony aggregates are being modified continually; in some places slowly, in others more rapidly, according to the attendant circumstances. The ever-changing physical conditions invariably set up continuous molecular shiftings in every rock, no matter what its composition or what its relations. The geological effects are significant. But this leads into a discussion of the phenomena of regional metamorphism, a subject which need only be mentioned in its general application in the present connection.

In biology the response of the organism to the modifications of climate, of food, of all the conditions of environment, is immediate, and the effects are quickly noticeable. Here the time element is short—within the compass of a single human life. In geology the time unit is long, not to be spanned by one, or even several, generations. The changes of the first kind are so rapid as to attract attention; those of the second are so gradual that, until very recently, they have escaped observation entirely. But the fact nevertheless remains.

There is a trite saying that has been widely quoted of late years. In substance it is that the changes undergone by rock-masses have been occasioned by the natural tendencies of minerals to assume combinations more stable from those less stable. Wadsworth[1] in particular has emphasized this point. But the statements have not carried with them their full import and meaning; for, in any particular case, while there is an attempt toward adjustment to satisfy a certain set of conditions, the conditions themselves continually change, sometimes in one direction, sometimes in another. In the production of these alterations in rock-masses time does not necessarily enter as a factor, although ordinarily the older a rock is the greater is the chance for disguising its primitive character. In attempting to determine the original conditions under which, for instance, an eruptive rock has solidified, the problem becomes more and more difficult in proportion to the amount of change, until finally a point is reached where it is absolutely impossible to say with certainty what the real nature of the stony mass was in the beginning.

These are some of the problems encountered at the outset in the study of the Maryland crystallines, especially the gneisses and schists.

[1] Nature, Vol. XXXV, p. 417, 1887.

In the consideration of the widespread effects of regional metamorphism, the agency of tangential pressure as the result of orographic movements is by no means the least important. Since the appearance of the classic work of Heim[1] the influence exerted by this one factor has become more and more clearly understood, as may be inferred from the writings of Bonney,[2] Hatch,[3] Lehmann,[4] Reush,[5] Törnebohm,[6] Schmidt,[7] Teal,[8] Williams,[9] and others.

Lehmann, in his work on the crystalline schists already referred to, called attention to certain mineralogical and chemical changes in rock-masses subjected to great pressure. In this country this phase of the subject has received the special consideration of Williams in his studies on the greenstone-schists of the Menominee and Marquette regions of Michigan. Briefly stated, the conclusions may be summarized in the following words:

> Whenever the crushing of rocks by dynamic agencies is accompanied, as it almost always is, by chemical action and the production of new minerals, these must arrange themselves in accordance with the existing strains. These secondary minerals are such as themselves possess a very perfect cleavage. Their production therefore, under circumstances of uniform and continued strain, will naturally impart a foliation to the originally massive rock. Nor is this all. The relief of the strain and the consequent crushing of the rock will take place among certain planes much more completely than along others; hence, in these planes the secondary minerals will be more abundant, and a banding of a once homogeneous rock may result.[10]

HISTORICAL CONSIDERATIONS.

But little has been published concerning the granites of Maryland. Notice of these rocks has been for the most part merely incidental and of little importance.

Among the earlier references to the granite masses under consideration may be mentioned that of P. T. Tyson.[11] During the period of his official connection with Maryland as agricultural chemist he made a tolerably complete geological map of the State. Along with other crystalline rocks, granite is spoken of in the accompanying explanations, but no detailed descriptions are given.

The United States census reports have given statistics concerning the quarry industry of the State, and brief descriptions of the chief localities where rocks are obtained; but no geological information of any consequence has ever been incorporated.

[1] Untersuch. über den Mech. der Geb., u. s.w., Band II, 1878.
[2] Quart Jour. Geol. Soc., London, Vol. XLII, 1886.
[3] Tsckermak's min. und petrog. Mitt., Bd. VII, 1885.
[4] Untersuch. über die Ent. der altkry. Schiefergesteine, u. s.w. 1884.
[5] Neues Jahrbuch, BB. V, 1887.
[6] Geol. För. Stockholm Förhandl., V, 1880.
[7] Neues Jahrbuch, BB. IV, 1886.
[8] Geological Magazine, Nov., 1886.
[9] Bull. U. S. Geol. Survey No. 28, 1886; also ibid., No. 62, 1890.
[10] Bull. U. S. Geol Survey No. 62, p. 206, Washington, 1890.
[11] First Ann. Rept. State Agri. Chemist of Maryland, 1860.

Williams has alluded briefly to these rocks at various times in connection with other crystallines of the State, yet has given incidentally the most valuable data heretofore published.

Lately Hobbs[1] has directed special attention to the allanite-bearing granitites of Ilchester.

Still more recently the occurrence of the hornblendic granites in the State has been recorded,[2] along with other facies of the prevailing granite types.

[1] Am. Jour. Sci. (3), Vol. XXXIII, p. 223, 1889.
[2] Bull. Geol. Soc. America, Vol. II, p. 321, 1891.

CHAPTER II.

GENERAL GEOLOGICAL FEATURES.

TOPOGRAPHY.

Topographically the Middle Atlantic slope has been aptly differentiated by McGee[1] into three easily recognizable and distinct districts, the central one of which, designated the Piedmont Plateau, being essentially a crystalline area. The geological features of this broad elevated plain contrast it sharply both with the Appalachian region to the westward, composed of folded Paleozoic strata, and with the coastal lowland to the eastward, made up of soft, incoherent sediments of much later date.

In Maryland the median watershed of the Piedmont region is called Parr Ridge, and rises from 600 to 900 feet above the sea-level. To the northward this ridge forms a prominent feature of surface relief, but in the southern part of the State the central divide merges into the general level of the plateau. In passing westward across the Piedmont Plain there is a gradual increase of elevation above mean tide from about 200 feet along the eastern boundary to twice or thrice this figure just before reaching the broad Frederick Valley, which separates the plateau from the first range of the Appalachian system. The interior of the Piedmont region of Maryland is gently undulatory, with small winding streams flowing in broad shallow valleys. Toward the margins of the elevated area, especially eastward, the rivers cut deep gorges before reaching the boundary line of the coastal deposits. All along these watercourses the crystalline rocks are well exposed in considerable variety.

LITHOLOGY.

Broadly speaking, the Piedmont Plateau in Maryland presents two rather well-defined lithological areas. The western half of the midland elevation consists principally of sericitic schists, with some arenaceous material. The eastern slope is made up chiefly of gneisses, with numerous intrusive rocks. Beginning with the eastern flank of the plateau, the holocrystalline rocks of Maryland occupy an extensive area immediately to the westward of a line connecting the cities of Wilmington, Baltimore, and Washington. This eastern limit is called the "fall line." It is at the head of all the tidal estuaries of the streams

[1] Am. Jour. Sci. (3), Vol XXXV, p. 121, 1888.

in the region, marks the great fault of the Piedmont zone, and forms approximately the boundary between the ancient, often highly metamorphosed masses and the younger, unconsolidated clastics of the Coastal Plain. Beyond the State boundaries, northward in Pennsylvania and New Jersey and southward in Virginia, the structural relations are practically the same.

The larger part of the great crystalline belt has been subjected to intense dynamic metamorphism, making it in some cases extremely difficult to distinguish clearly between those rocks which are truly igneous in nature and those which are highly altered sediments. There is, however, a large portion of the crystallines whose eruptive nature is beyond all reasonable doubt. Their superficial extension is about 1,000 square miles. They are quite varied. Those thus far recognized may be classed into three principal categories:

(1) Basic rocks; including, as shown by Williams,[1] pyroxenite, lherzolite, cortlandtite, and their alteration products, steatite and serpentine.

(2) Intermediate rocks; comprising, according to the same authority, hypersthene-gabbro, gabbro-diorite, quartz-gabbro, norite, diorite, and hornblendite.

(3) Acid rocks; embracing binary granite, granitite, allanite-epidote granite, and hornblende granite; with the structural varieties of porphyritic granite, granitic augen-gneiss, felsite, pegmatite, and graphic granite.

The last of the three groups mentioned includes the types receiving special consideration in the following pages. Geographically they form thirteen more or less distinct and separate areas, which for present convenience take their names from the chief places within their respective borders. The areas are represented on the accompanying map (Pl. XXXVI.)

GEOLOGICAL STRUCTURE.

Recently[2] a rather detailed geological section was made across the Piedmont Plateau in southern Maryland from Washington to Point of Rocks (Pl. XXXVII, fig. 1). East and west sections in the midland region of the State present essentially the same features. The broad limestone belt between Catoctin and Sugarloaf is probably Trenton,[3] and is the most easterly of the older calcareous deposits whose age is definitely known, although the massive sandstone which caps Sugarloaf Mountain and dips at a comparatively small angle to the eastward is, from its resemblance to that of Catoctin Mountain, in all probability Cambrian. By the intercalation of numerous thin argillaceous bands the great sandstone rapidly loses its sandy character upward, and passes gradually into typical phyllites. These schistose rocks, in broad,

[1] American Geologist, Vol. VI, p. 40, 1890.
[2] Geol. Soc. America, Bull., Vol. II, pp. 319–322, 1891.
[3] Johns Hopkins Univ. Circulars, Vol. X, p. 32, 1890.

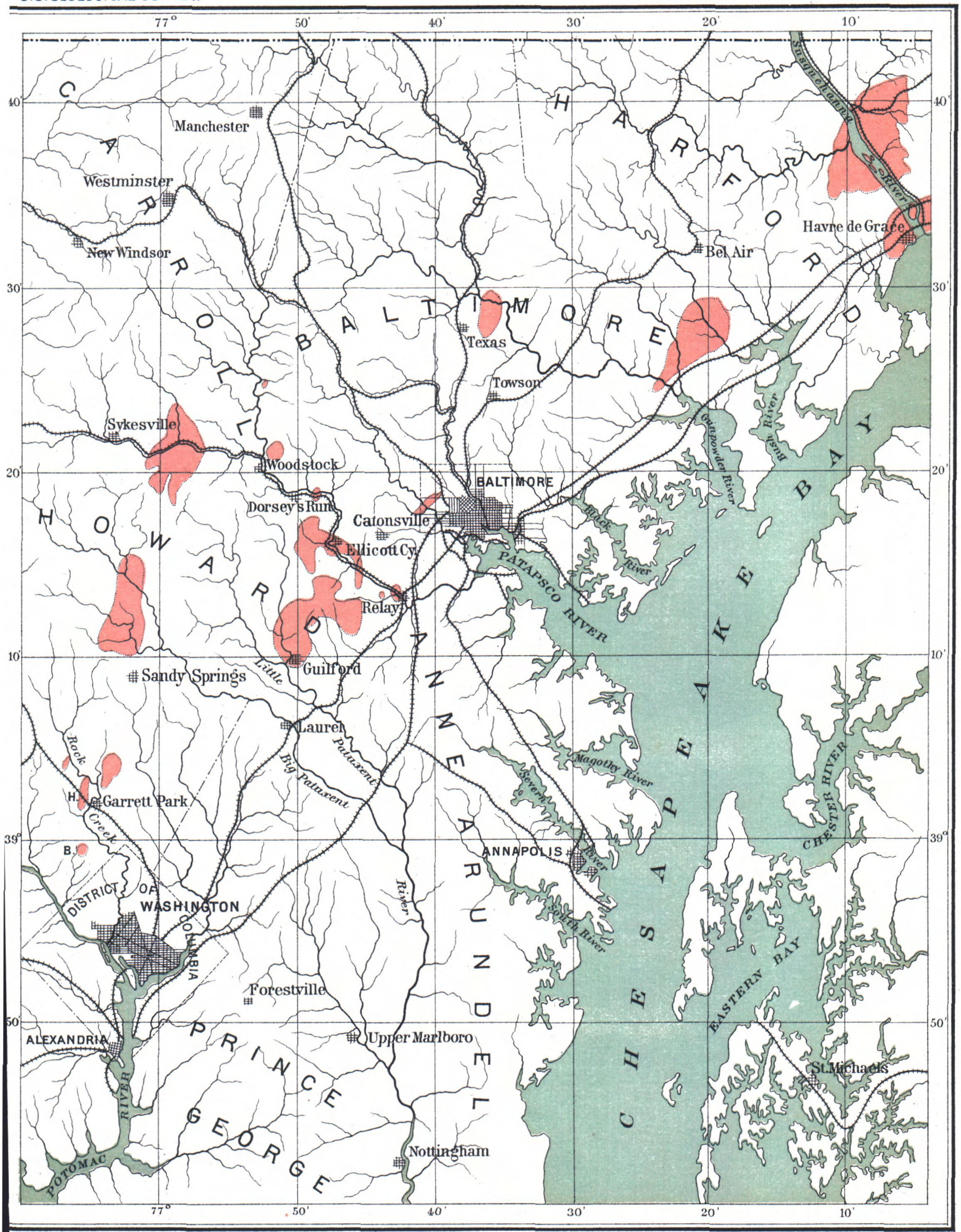
alternating hydromicaceous and chloritic belts, have a superficial extension halfway across the plateau. At first the cleavage planes have a low angle and are parallel to the inclination of the great sandstone; but gradually the inclination becomes greater and greater, until near the axis at Derwood Station, on the Metropolitan Branch of the Baltimore and Ohio Railroad, it is perpendicular. Near Sugarloaf these planes have the appearance of being coincident with the lines of stratification, but eastward the schists are very much puckered. The area is broken through in several places by Mesozoic diabases.

East of the axis the rocks are contorted gneisses, with westerly dips; nearly perpendicular at first, but by degrees assuming lower and lower angles. Several narrow serpentine belts traverse these rocks, which are also disturbed in numberless places by other eruptives. To all appearances the gneisses were originally largely granitic, but through the agency of enormous orographic pressure have been squeezed into their present gneissic condition. This is well shown by the microscopical examination of thin slices of the rock. The mineralogical constituents all present great mechanical deformation, the edges and angles being ground away, with the fragments still visible filling the interstices. The larger quartz grains exhibit, between crossed nicols, marked undulatory extinction, a phenomenon quite characteristic of granite masses which have been subjected to great dynamic action.

In the northern part of the State the intrusive rocks are much more numerous than in the southern portion. Several very different interpretations have been given to the structure of the region under consideration, as shown in a general way in figs. 1 and 2 on Pl. XXXVII. Dr. Williams[1] has already summarized these several hypotheses. The one that seems to accord best at present with the observed facts and that is in every way most satisfactory may be reiterated briefly, though it will probably require some modification before furnishing an explanation entirely in harmony in all details.

The complex geological structure of the Piedmont zone plainly shows that the rocks have been greatly disturbed at various times both prior and subsequent to the early baseleveling of the region, when the crystallines formed the foundations upon which the more westerly sediments were laid down. In the process of many foldings some of the clastics became involved and infolded with the massives, and both were then subjected to the more or less intense dynamic action of the later orographic disturbances. Operating to still further obliterate the original character of the rocks was the influence of the numerous intrusives which are known to have broken through at various periods. Broadly speaking, the gabbro and dioritic types seem to be the first to have been extensively intruded. These were followed by the more basic nonfeldspathic rocks. Then at different intervals the granite types appeared, breaking through all of the preceding series.

[1] Bull. Geol. Soc. America, Vol. II, pp. 315-317, 1891.



MAP OF CENTRAL MARYLAND SHOWING THE DISTRIBUTION OF THE GRANITES.

BY

G. H. WILLIAMS

1892.

Scale 0 2 4 6 8 16 24 32 MILES.

PLATE XXXVII.

PLATE XXXVII. GEOLOGICAL SECTIONS ACROSS THE PIEDMONT PLATEAU OF MARYLAND.

Fig. 1.—Section along the Metropolitan Branch of the Baltimore and Ohio Railroad, from Point of Rocks to Washington. c = Catoctin sandstone; *n* = Newark (Triassic) red sandstone, with northwesterly *dips*; *l* = Frederick limestone; *sh* = hydromicaceous and chloritic schists; *sl* = slates; *d* = Mesozoic diabase dike; *d′* = Buck Lodge diabase; *d″* = diabase dike; *s* = serpentine (two belts); *a* = axis, near Derwood Station; SL = Sugar Loaf sandstone; *gn* = gneiss; *g* = granitoid gneiss; *g′* = granite, in part hornblendic; *p* = Potomac clays and coastal deposits.

Fig. 2.—Section along the main stem of the Baltimore and Ohio Railroad, from Baltimore to Frederick. (Modified from Williams.) Same lettering as in fig. 1, except: *p* = pyroxenite; *gb* = gabbro.

Fig. 3.—Section of railway cut at Dorsey Run Station, main stem of Baltimore and Ohio Railroad. Height, 40 feet; length, 300 feet; 1, 8, and 12, massive granite with large fragments of gneiss; 2, 4, 6, 10, 11, and 13, dark-colored gneiss; 3 and 5, very acid granite dikes; 7, 9, and 15, massive granite; 14, 16, pegmatite.

FIG. 1

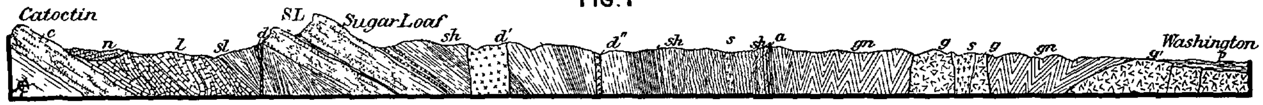
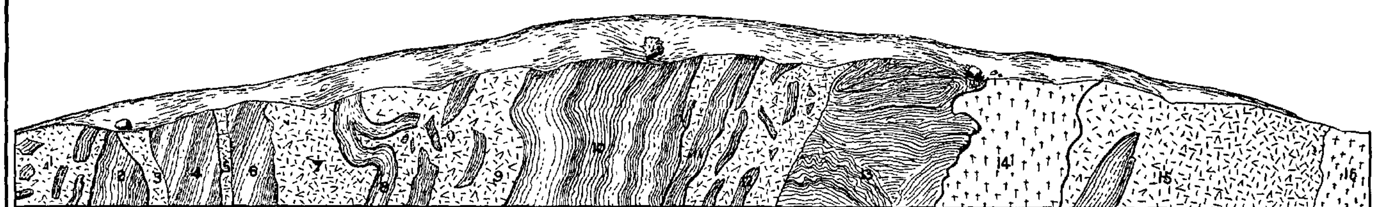


FIG. 2.

FIG. 3.



GEOLOGICAL SECTIONS ACROSS THE PIEDMONT PLATEAU OF MARYLAND.

Enormous denundation has greatly obscured many of the phases in the geological history of the region, which to-day apparently represents an ancient mountain range that has been repeatedly raised, baseleveled through great erosion, and is again being slowly elevated, to be eaten away. As recently shown by McGee,[1] the rising of the Piedmont region is manifested in the declinations of the streams immediately to the west of the "fall line," where the watercourses have formed for themselves canyons of considerable depth. Furthermore, the sinking of the land to the eastward of the line mentioned is shown in the drowning of the river basins of the Coastal Plain district. It is estimated by the writer mentioned that the rate of elevation of the Piedmont zone is probably about as rapid as has ever been attained in any part of the globe during any geological period.[2]

---

[1] U. S. Geol. Survey, 7th Ann. Rept., pp. 618, 619, 1889. [2] Ibid., p. 625.

CHAPTER III.

PETROGRAPHY.

GENERAL CHARACTERS.

Throughout the holocrystalline zone of Maryland dynamic action has operated more or less intensely upon all the rocks. There is evidence to prove that there were several periods of disturbance, widely separated in point of time. The forces in operation at the different periods, while much the same in their general effects, have not always displayed the same intensity nor produced the same results. The repeated dynamic movements have tended to disguise the original characters of the different rock masses, the degree of change being in a general way proportional to the time elapsed since the influences were felt. As a rule, then, among rocks of the same kind, the oldest show the greatest amount of alteration. Upon structural grounds, therefore, the acidic crystallines, or granite rocks, are broadly divisible into two great groups: those having the original character highly altered and those in which the primitive structure has not been greatly obscured. To the first of these classes belong the gneisses, very much older than the others, and occupying the greater part of the eastern Piedmont region. With the second may be classed the undoubtedly eruptive granites, of which there are several varietal types.

The rocks of the latter class form the especial subject of this paper. They are light-ash to dark-gray in color, rather fine-grained, as a rule, and very compact. As in all granites, their mineralogical composition is not very complex, yet their petrography offers some very suggestive considerations.

CHEMICAL COMPOSITION.

The chemical composition of the different granites studied accords with the general conclusions arrived at from microscopical examinations, as well as with deductions made in the field. These relations will be more fully referred to in connection with the remarks on the various rock types and their several occurrences.

A few analyses of the most typical Maryland granites, made by Mr. W. F. Hillebrand, of the U. S. Geological Survey, are given in the accompanying table. The first four are here introduced to show at the outset the general chemical characters of the rocks principally dealt with. The bearing of these and other analyses is more fully discussed later.

Table of chemical analyses of Maryland granites.

	I. Guilford.	II. Sykesville.	III. Woodstock.	IV. Dorsey Run.	V. Dorsey Run gneiss.
SiO_2	72.57	71.45	71.79	70.45	48.92
Al_2O_3 *a*	15.11	14.36	15.00	15.98	16.57
Fe_2O_3	.59	2.07	.77	.75	4.21
FeO	1.02	2.78	1.12	1.84	9.18
CaO	1.65	1.58	2.50	2.60	9.69
MgO	.30	1.17	.51	.77	5.98
K_2O	4.33	3.28	4.75	3.59	1.56
Na_2O	3.92	1.95	3.09	3.83	2.47
Li_2O	Trace.	Trace.	Trace.	Trace	Trace.
N_2O	.47	1.30	.64	.45	1.68
Total	99.96	99.94	100.17	100.26	100.26

a Includes all TiO_2 and P_2O_3.

No. I is the Guilford rock, a true binary granite. It corresponds closely with analyses of the "Echte Granit" from the typical localities in Germany and other parts of Europe. Its poorness in iron and ferro-magnesian silicates is readily seen in the thin sections and in hand specimens by the light color, as well as in the chemical analysis.

No. II is from the typical granite occurrence at Sykesville, a mass which has been considerably crushed and squeezed, until now it is quite gneissose in character. It still retains abundant inclusions of other kinds of rock. In this granite allanite, so abundant in the Woodstock and Dorsey Run areas, occurs very sparingly or not at all.

No. III is the Woodstock granite. While its acidity is almost the same as the Sykesville rock, the presence of considerable allanite and epidote, seen so plainly in thin sections, is indicated by the marked increase in the percentage of CaO.

No. IV is an analysis of a number of selected pieces of light-colored dikes, which penetrate both the massive granite and the associated gneiss at Dorsey Run. The fragments were all about the same size and were taken from different parts of the exposure. They were then pulverized and thoroughly mixed, in order to get an average sample for chemical examination. The larger and more massive portions of the intrusive granitic rocks, which were also analyzed, show a somewhat lower percentage of SiO_2 than the narrow dikes. The greater acidity of the latter as compared with the similarly constituted masses through which they break is in full corroboration of Rosenbusch's theory of dikes.

No. V is from the acid gneiss through which the granite which No. IV represents has been thrust. Its very basic character is especially noteworthy. Analyses of inclusions of this gneiss embedded in the granite give a SiO_2 per cent about midway between the gneiss and the granite, showing that considerable silica has penetrated the gneiss fragments.

With the exception of No. V the analyses clearly show that the rocks are all normal granites. The gneiss differs so widely chemically from any known eruptive magma that its composition strongly suggests its sedimentary origin, in accordance with the principles recently laid down by Rosenbusch in his Auffassung der Chemischen Natur des Grundgebirges.[1]

MINERALOGICAL CONSTITUTION.

The great bulk of the Maryland acid rocks is made up of a mixture of quartz and feldspar, the latter being usually orthoclase. In the majority of granites under discussion biotite enters largely as a constituent. Besides these there occur, in much more limited quantities, plagioclase, microcline, magnetite, apatite, zircon, epidote, allanite, hornblende, muscovite, sphene, and occasionally some other minerals. Along the lines of contact with older rocks various metamorphic products are abundant. Among these may be mentioned garnet, epidote, and tourmaline. Various other secondary minerals also make their appearance as the result of regional metamorphism or weathering; such are epidote, muscovite, zeolites, pyrite, ripidolite, and saussurite.

The minerals which are to be considered as making up the granitic rocks of Maryland may be regarded as belonging to five categories; the first three are to be regarded as original or primary, the last two as secondary. The groups may be taken up in order of their sequence of crystallization.

First of all, there are those minerals which have manifestly crystallized out of the molten magma before the ferro-magnesian components. They occur in small quantities, and may be classed as accessory constituents. In the second place, there are those minerals whose period of crystallization is contemporaneous with the biotite, the leading iron-bearing compound. These are to be regarded as essential constituents in the granitic types in which they occur. The third group contains all the principal essential minerals which make up by far the larger part of the rocks under consideration. The secondary constituents include two classes, one embracing those minerals whose origin is due to the contact action of eruptives on the rocks through which they have broken, and the other those minerals whose genesis is the result of the breaking down of other minerals under metamorphic or atmospheric influences.

[1] Tschermak's Mitt. f. Pet. u. Min., XII Bd., p. 49, 1891.

The classification is as follows:

Original.
- I. Accessory.
  - Magnetite.
  - Apatite.
  - Zircon.
  - Sphene.
- II. Essential (in types where they occur, the last four contemporary with biotite).
  - Biotite.
  - Muscovite.
  - Hornblende.
  - Allanite.
  - Epidote.
- III. Essential (principal).
  - Plagioclase.
  - Orthoclase.
  - Microcline.
  - Quartz.

Secondary.
- IV. Through contact.
  - Garnet.
  - Epidote.
  - Tourmaline.
- V. Through weathering.
  - Muscovite.
  - Ripidolite.
  - Limonite.
  - Calcite.
  - Pyrite.

MAGNETITE.

Although thin slices under the microscope indicate only occasional specks of magnetite, this mineral is quite abundant in some of the Maryland granites. Careful panning of the pulverized rock, or of granitic sand derived from the breaking down of granites in situ, concentrates considerable quantities, which is usually in octahedrons varying from microscopic dimensions up to 1 or even 2 mm. TiO_2 may be present in some of the magnetites, but as yet this has not been proved by chemical analysis.

APATITE.

There is nothing especially noteworthy about the phosphate constituent of the granite. Crystals are not abundant, but when present show all the ordinary optical properties observable in granite occurrences. The grains are minute, with the common bounding planes more or less distinctly discernible. In panning the pulverized rock, the apatite, on account of its high specific gravity, remains behind, along with the minerals containing the metallic bases, and thus it may be readily and quickly concentrated. Rounded grains are occasionally seen in the gneisses of the region, which are alluded to in another place.

ZIRCON.

Zircon shows the characters usual in granitic occurrences. The crystals are all very minute and appear as inclusions in other constituents; they are therefore, like the apatites, among the earliest minerals to crystallize from the granitic magma. For the most part they are perfectly colorless, though in some cases a faint yellow tinge is perceptible. In some of the rocks which have been affected by great pressure, crystals of zircon are occasionally met with showing cataclastic fracture. One of these is represented in fig. 6, Pl. XXXVIII.

SPHENE.

This mineral is perhaps most abundant in the porphyritic granites of the Ellicott City district. It occurs in well-defined crystals of the "lederite" type. The bounding planes are glistening and intersect in sharp edges. The crystallographic faces usually observed are (Dana's position):

OP well developed.
P very large.
∞P very narrow.
$+mP\bar{\infty}$ small, probably $+2P\bar{\infty}$.
$-mP\bar{\infty}$ small, probably $-2P\bar{\infty}$.
$\infty P\bar{\infty}$ minute.

In size, crystals having measurements of 3 to 5 mm. are abundant, and from this maximum they range down to microscopic dimensions.

In thin sections under the microscope this mineral has a decided reddish tinge. The dark marginal zones due to the high index of refraction are very wide, even broader than in epidote. Fig. 2, Pl. XL, shows a sphene crystal with included epidote and apatite, and the relative difference in the refractive index is easily compared. Pleochroism is not marked.

BIOTITE.

In all the granites of the State, biotite is the important ferro-magnesian constituent. In some of the facies this mineral is partially replaced by hornblende; in others epidote-allanite or muscovite are prominently associated with it. It is this ingredient which gives the granites their different shades of color, causing them to vary from the very light ash-gray rocks of Halpin or Guilford to the dark-hued occurrence of Dorsey Run. Under the microscope numerous inclusions of older minerals are noticeable in the biotite; among these the most important are magnetite, epidote, allanite-epidote intergrowths, zircon, and apatite.

MUSCOVITE.

Muscovite is generally regarded as one of the essential constituents of binary or "true" granite. These rocks occur in a number of places, where they have been thoroughly studied in all details by many investigators. Until quite recently the occurrence of original muscovite in

PLATE XXXVIII.

PLATE XXXVIII. THIN SLICES OF MARYLAND GRANITES.

Fig. 1.—Epidote crystal, with included apatite, Ellicott City. *f* = feldspar; *b* = biotite; *q* = quartz; *e* = epidote; *a* = apatite. Also, at the lower left-hand quarter, a rounded micropegmatitic grain. (x 30.)

Fig. 2.—Epidote crystals in Woodstock granites. Same lettering as in fig. 1. (x 30.)

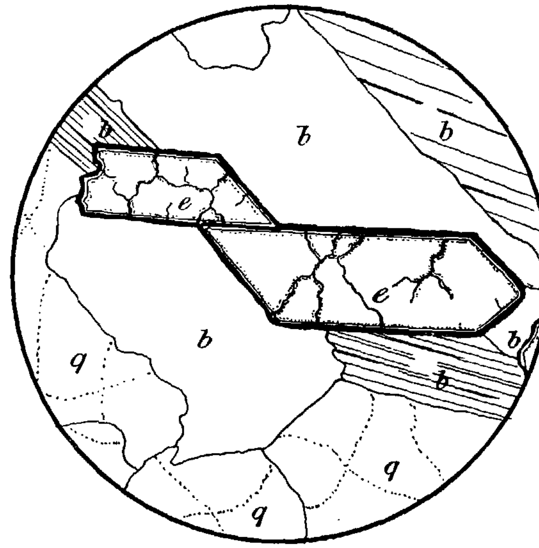
Fig. 3.—Epidote crystals in Woodstock granites. (x 30.)

Fig. 4.—Epidote-allanite intergrowths in Ilchester granite (after Hobbs): the allanite cores showing zonal structure.

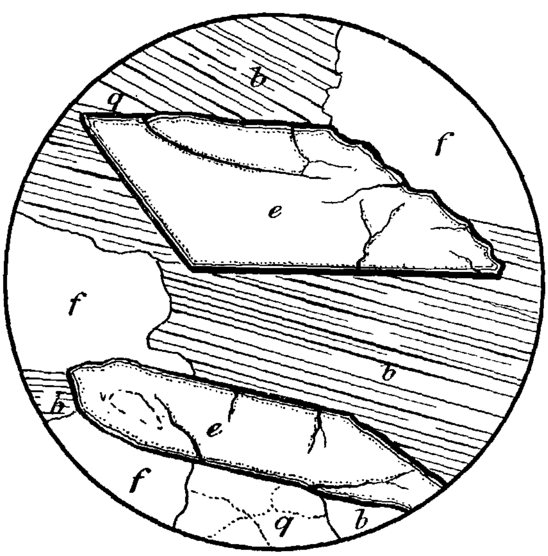
Fig. 5.—Muscovite in granite from Guilford; showing also micropegmatitic grain. (x 30.)

Fig. 6.—Cataclastic zircon in bent muscovite plate; from pressed granites at Ellicott City. (x 150.)

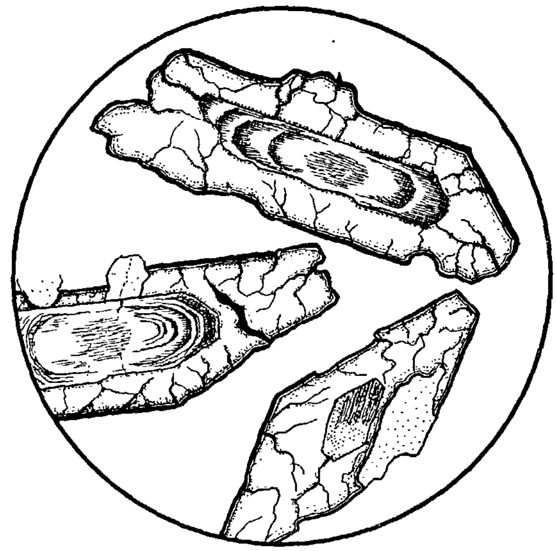
1



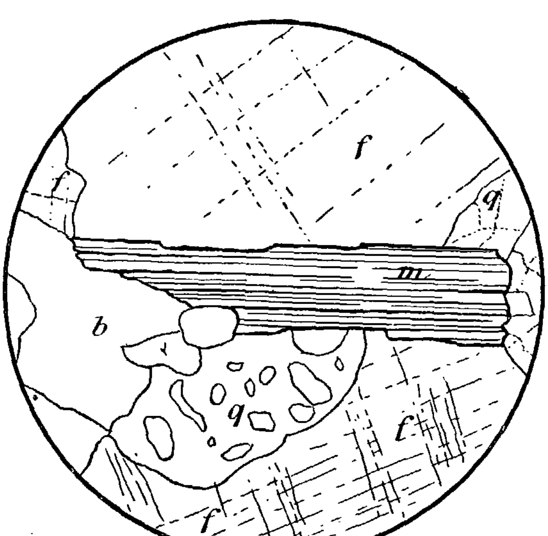
2



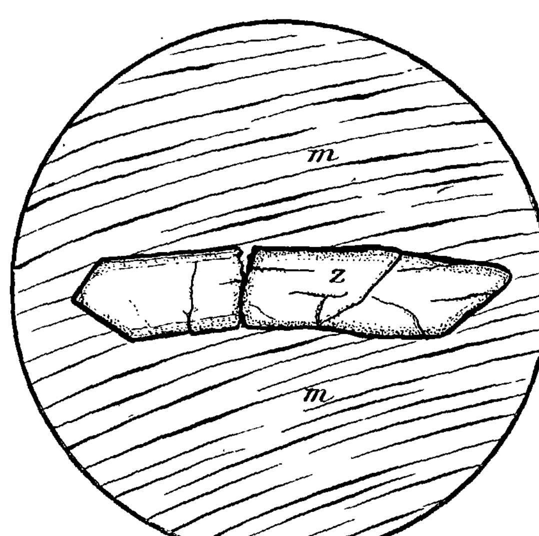
3



4



5



6

THIN SECTIONS OF MARYLAND GRANITE.

granites scarcely raised a doubt, but it has lately been questioned whether muscovite actually does appear in any eruptive granites as a primary component. Considerable interest therefore attaches to the granitic rocks of Guilford, in Howard County, which contain large quantities of muscovite. This occurrence is regarded as a true binary granite (Echte Granit of the Germans).

There are good reasons for believing that the muscovite in certain of the Maryland granites is not of secondary origin. The rock just alluded to as occurring near Guilford seems to have been affected but little by dynamic influences, and consequently it is among the least metamorphosed of the eruptives in the State. No signs of decomposition are visible in any of the mineral constituents. The biotite is especially fresh. White mica in large, clear, sharply bounded flakes occurs abundantly throughout the rock. Under the microscope all the physical characters usually ascribed to muscovite may be made out. The plates are transparent, with often a faint yellowish tinge. In many flakes there is an absorption of the light rays vibrating with the cleavage which is quite noticeable. The muscovite is intimately associated with the biotite, often large groups of the two micas being found mixed together indiscriminately, but preserving perfectly the individuality of the separate crystals.

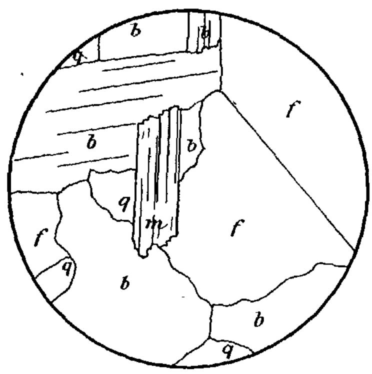


FIG. 23—Thin section of Guilford granite.

In many instances the muscovite is the older of the two micas and conditions the form of the biotite. In other cases the muscovite forms sharply defined plates, around which the biotite, in single crystals, forms nearly a complete mantle; or the two micas not unfrequently form parallel growths; and occasionally clear muscovite flakes penetrate biotite grains at various angles. Some of these examples are best illustrated by means of drawings, as shown in fig. 23 and in Pl. XXXIX, figs. 4, 5, and 6.

The relations of the light and dark colored micas to each other leave but little doubt that the two minerals crystallized contemporaneously. In some places the latter was the first to assume definite proportions; elsewhere the former appeared first. The association of the muscovite and feldspars is much the same. The first-mentioned mineral frequently gives form to the latter. White mica plates also cut across feldspar crystals, extending on either side a considerable distance into other constituents. In specimens taken from near the surface of the granitic mass, where alteration has begun in the feldspar, small irregular flakes of muscovite are developed. They stand out sharply against the larger plates of the same mineral, which cut all constituents alike. The small mica areas in the feldspar are very irregular in outline, cloudy in appearance, and have their cleavage lines less prominently developed. They are manifestly secondary products of the feldspathic components. In sharp contrast to these, the large plates of white mica, which correspond in every respect to the muscovite characteristic of the wholly unaltered rock whose feldspars are not affected, still remain clear and retain their distinct boundaries. Here, then, are apparently muscovite flakes in the same hand specimens, some evidently original, some manifestly secondary. In certain pegmatites which are of eruptive origin, large plates of black mica (lepidomelane) occur, in which large thick crystals of white mica are firmly embedded, clearly indicating that the light-colored mica was the first to crystallize.

Wherever dynamic metamorphism has begun to develop muscovite at the expense of the other constituents of the granite, difficulty is naturally encountered in attempting to prove whether or not there was any original white mica present, and in many cases it is practically impossible to reach any positive conclusion. Yet there are cases which seem to point strongly to the original nature of muscovite in other of the Maryland granitic masses. The granite of Ellicott City contains an occasional large flake of white mica, bent and twisted as the result of gradual movement of the mass after complete consolidation. One thin section in particular is instructive, and is shown in the accompanying fig. 24. The larger muscovite flake contains a long zircon crystal which was manifestly broken and faulted at the same time that the mica plate was bent. An enlarged view of the same crystal is shown in fig. 6, Pl. XXXVIII.

FIG. 24.—Thin section of squeezed Ellicott granite

Muscovite of secondary origin, formed by the decomposition of feldspar and from the bleaching of the dark mica or the leaching out of its iron, is an abundant mineral in most of the acid rocks under consideration, especially in those granites which exhibit incipient stages of alteration, due either to orographic pressure or ordinary weathering. The light-colored micas, resulting from the breaking down of essential constituents, need but passing mention here, for they offer no striking peculiarities distinguishing them from the same minerals as they occur in other granitic rocks.

ALLANITE.

Allanite has been long regarded as one of the rarer rock-forming minerals. Within the past few years, however, Iddings and Cross[1] have

[1]Am. Jour. Sci. (3), Vol. XXX, p. 108, 1885.

Fig. 1.

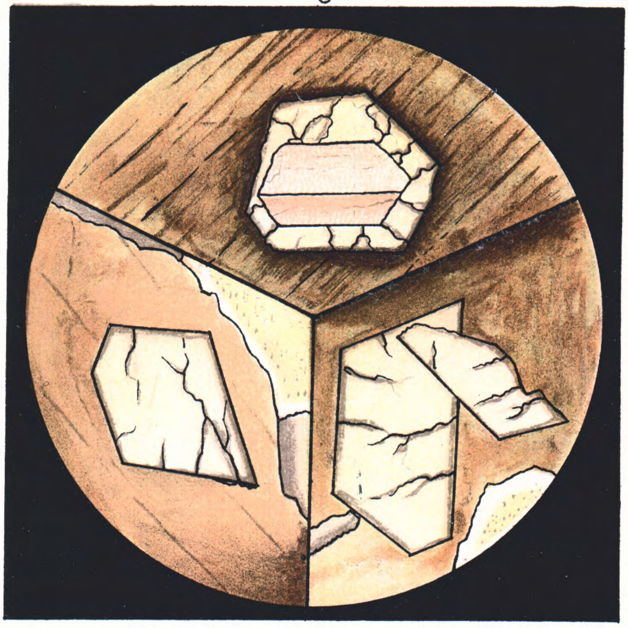


Fig. 2. Fig. 3.

Fig 4.

Fig. 5. Fig. 6.

THIN SECTIONS OF MARYLAND GRANITE.

found this silicate of the rare earths widely distributed among acid eruptives, in some of which it forms an important accessory constituent. Among the rocks in which this mineral was found may be mentioned gneiss, granite, quartz-porphyry, rhyolite, diorite, porphyrite, andesite, and dacite. The localities in this country where allanite has been found to form a rock constituent are numerous, and are geographically widely separated.

In Europe the apparent rarity of rock-forming allanite has made the observed occurrences somewhat noteworthy. There is a further interest centered around this mineral which is of importance from an historical point of view also; it is the fact that the presence of allanite in granite formed one of the chief arguments against the igneous origin of granite in the long-continued controversy that took place during the second quarter of the present century. The fact that this mineral could not withstand a temperature higher than a dull-red heat without changing its physical character was evidenced as a strong proof against the igneous origin of granite. This objection, however, was met by Scheerer[1] as early as 1842, in a paper entitled "Erste Fortsetzung der Untersuchungen über Gadolinit, Allanit, und damit verwandte Mineralien," read at Stockholm before the Society of Scandinavian Naturalists. Some years later the same writer[2] discussed an aquo-igneous theory of the origin of granite, and suggested that owing to the presence of water the magma may cool down considerably below the temperature necessary for solidification under the conditions of ordinary dry fusion, and thus allow minerals which can not endure great heat to crystallize out before other constituents more difficult to fuse by the simple dry method. Both Élie de Beaumont and Daubrée, as well as some more recent investigators, have experimentally confirmed this theory.

Since Scheerer's time a number of writers have noted the occurrence of allanite in various igneous rocks. Chief among these may be mentioned Bloomstrand,[3] Von Fritsch,[4] Vom Rath,[5] Liebisch,[6] Törnebohm,[7] Iddings and Cross,[8] Michel-Lévy and Lacroix,[9] Hobbs,[10] Lacroix,[11] and Keyes.[12]

Hobbs was the first to call attention to the presence of allanite in the rocks of Maryland. The specimens especially studied were from

[1]Poggendorff's Annalen der Phy. u. Chemie, LVI Band, p. 479, 1842.
[2]Bull. Soc. géol. de France (2), t. IV, p. 468, 1847.
[3]Oefvers. af. akad. Förhandl., No. 9, p. 296, 1854.
[4]Zeitsch. d. d. geol. Ges., XII, Band, p. 105, 1860.
[5]Zeitsch. d. d. geol. Ges., XVI, p. 255, 1864.
[6]Zeitsch. d. d. geol. Ges., XXIX Band, p. 725, 1877.
[7]Geol. Fören. i Stockholm Förhandl., VI Bd., p. 185, 1882; also, Vega Exp., Vol. IV, p. 115, 1884.
[8]Am. Jour. Sci. (3), Vol. XXX, p. 108, 1885.
[9]Bull. Soc. min. de France, t. XI, p. 65, 1888.
[10]Johns Hopkins Univ. Circulars, No. 65, p. 70, 1888; also, Am. Jour. Sci. (3), Vol. XXXVIII, p. 223, 1889; also, Tschermak's min. und. petrog. Mitth., XI Bd., p. 1, 1890.
[11]Bull. Soc. min. de France, t. XII, p. 139, 1889.
[12]Bull. Geol. Soc. Am., Vol. IV, p. 306, 1893.

the granite and granite-porphyry occurring near Ilchester. Since the announcement of these occurrences similar allanites and allanite-epidote intergrowths have been found at other places—at Dorsey Run Station, and in less abundance at Woodstock and on the Gunpowder River, northeast of Baltimore.

Macroscopically the allanites are seen as minute, bright-reddish specks, generally inclosed in epidote. Under a hand glass they appear as small, more or less elongated columns, having the faces well developed, with uneven fracture and an oily luster. They are quite brittle, making it almost impossible to completely separate fragments from the surrounding mineral.

In thin sections the crystals are transparent, with yellowish or reddish-brown tints, and stand out in marked contrast against the clear yellowish background of epidote, with which they form parallel intergrowths. The planes of the orthodiagonal zone are usually well developed, but terminal faces as a rule are poorly defined. Twins are of frequent occurrence, the twinning plane being the orthopinacoid. The pleochroism is very marked, $\mathfrak{a}$ being nearly colorless, or slightly brownish; $\mathfrak{b}$, reddish-brown; $\mathfrak{c}$, yellow or greenish-brown. The absorption is therefore similar to epidote: $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The index of refraction is rather high; the double refraction weak, giving low interference colors between crossed nicols. The plane of the optic axes lies in the clinopinacoid ($\infty P \grave{\infty}$).

EPIDOTE.

The general remarks that have just been made concerning allanite apply also in a great measure to certain epidotes, especially those which occur at Woodstock, Ilchester, Ellicott City, and Dorsey Run Station. At all of these places the epidote is found in irregular grains, sharply bounded crystals, and in isomorphous growths with allanite.

As already stated in connection with allanite, the occurrence in Maryland was first made known by Hobbs.[1] But since the appearance of the first note on the allanite-epidote intergrowths from the porphyritic granite of the Ilchester district, some doubts have been raised as to whether the exterior clear portions of the grains are not in reality the same mineral as the interior dark parts, but differing slightly chemically. For this reason the author[2] just referred to reexamined some of his earlier preparations, and after the complete isolation of the dark central allanite, had a chemical analysis made of the epidote powder. This agrees well with epidote analyses of other localities, particularly with Ludwig's analysis of a specimen from Untersulzbachthal. The following are the results obtained by Hillebrand from the Maryland material and by Ludwig from the Tyrolese locality. The TiO_2 is proba-

[1] Johns Hopkins Univ. Circulars, No. 65, p. 69, 1888.
[2] Am. Jour. Sci. (3), Vol. XXXVIII, pp. 223-228, 1889.

bly due to the presence of sphene, which was not separated completely from the powder:

	Maryland.[1]	Untersulz-bach.
SiO_2	37.63	37.83
Al_2O_3	18.40	22.63
TiO_2	3.78	....
Fe_2O_3 }	15.29	{ 15.02
FeO }		{ .93
MnO	.31	....
CaO	22.93	23.27
MgO	.31	....
P_2O_5	.44	....
H_2O	2.23	2.05
Total	101.32	101.73

[1] See also Bull. 64, U. S. Geol. Survey, p. 42.

The epidote of the allanite-bearing granites of Maryland is frequently so abundant as to give a decided greenish cast to the color of the rock. Under a pocket lens the yellowish-green mineral is seen in small, sharply bounded crystals or irregular grains, showing glistening surfaces of fracture and usually containing a central reddish interior of allanite.

Under the microscope the epidote usually appears in sharply defined crystals, or grains, enveloping reddish cores of allanite, with which they are similarly oriented. Twins have not been observed, though the included mineral is often twinned. The sections are transparent, colorless, or slightly yellowish, with imperfect cleavage. The pleochroism is quite marked for rock-making epidote, $\mathfrak{a}$ being colorless, or very faint yellowish; $\mathfrak{b}$ light-yellow, often tinged with green; $\mathfrak{c}$ greenish-yellow. The absorption is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. Interference colors brilliant. The plane of the optic axes is perpendicular to the cleavage and direction of elongation. These characters and the chemical analyses given correspond in all particulars with those of rock-making epidote.

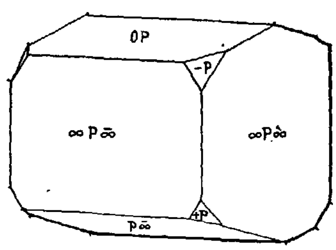


FIG. 25—Crystal of epidote in Ellicott granite.

The parallel growths of epidote and allanite have been discussed elsewhere in connection with remarks on the latter mineral.

The simple crystals of epidote are usually quite small, and commonly have their crystallographic planes much better defined than in the other cases. The most frequently observed faces appear to be OP {001}, $\infty P \bar{\infty}$ {100}, $P \bar{\infty}$ {001}, $\infty P \breve{\infty}$ {010}, and occasionally two small hemipyramids, probably + P {$\bar{1}$11} and − P {111}. (See fig. 25. These crystals were not measured, and the figure represents one as it appears under the microscope.) The crystals, as well as many of the intergrowths with allanite, occur as a rule completely surrounded by biotite, as is shown in figs. 1, 2, and 3, Pl. XXXVIII, and figs. 1, 2, and 3, Pl. XXXIX. Fig. 1, Pl. XXXVIII, also shows an included apatite. Fig. 2, Pl. XL, illustrates an interesting occurrence of epidote as an inclusion in sphene, along with an apatite. In other masses the sharply bounded epidote comes in contact with unaltered feldspar, quartz, and biotite grains, and gives outlines to them.

The allotriomorphic grains of epidote are not common in any of the four granite districts mentioned. Usually one or more of the crystal boundaries may be made out. These also often contain allanite cores.

The origin of the epidote in the Maryland granites is of great interest. Rock-making epidote has heretofore been almost universally regarded as a secondary constituent in igneous eruptive rocks. In contact zones of certain eruptives with calcareous beds this mineral is formed. It is abundantly developed in metamorphic gneisses, schists, and phyllites, as a characteristic ingredient. It is also a common decomposition product of both acid and basic rocks containing feldspar.

The existence of epidote in acid eruptives has occasioned considerable discussion. Among the earlier references may be mentioned papers of Becher[1] and Bloomstrand,[2] while the principal allusions to the subject during the past decade have been made by Törnebohm,[3] Geikie,[4] Hobbs,[5] Adams,[6] and Rosenbusch.[7]

The general consensus of opinion, as derived from the literature referred to, has been against the idea that the epidote was original in any of the cases mentioned. Hobbs,[5] who was the first to study the Ilchester (Maryland) granite, was inclined to believe that the epidote was of metamorphic origin. Very recently Adams[6] has investigated some epidote-bearing granites from Alaska, in which the mineral alluded to is thought to result from the recrystallization of certain of the rock constituents after the original solidification of the mass. The epidote is regarded as "having grown into the surrounding minerals by first sending out little arm-like extensions of its substance which subsequently met one another, in this way including some of the foreign minerals which may or may not finally disappear" (p. 349). Parallel growths of allanite and epidote are explained by the former being regarded as "a primary mineral, around which the epidote would naturally crystallize, if any were developed in the rock, the two minerals being isomorphous" (p. 350).

Rosenbusch, in the last edition of his Microscopische Physiographie, issued a short time ago, distinctly states[8] that this mineral never occurs as an original constituent in eruptive rocks.

On the other hand, there have been a number of examples of epidote

[1] Ueber das Mineralvorkommen in Granit von Striegau, u. s. w.
[2] Oefvers af. akad. Förhandl., No. 9, p. 296, 1854.
[3] Geol. För. i. Stockholm Förhandl., VI, p. 245, 1892.
[4] Quart. Jour. Geol. Soc., Vol. XXXIX, p. 314.
[5] Johns Hopkins Univ. Circulars, No. 65, p. 70, 1888; also Am. Jour. Sci. (3), Vol. XXXVIII, pp. 223–228, 1889.
[6] Canadian Record Sci., 1891, pp. 344–358, 1891.
[7] Mik. Phys., 3d ed., I Band, p. 610, 1892.
[8] Loc. cit.

noted of later years in eruptive rocks in which it has been thought that the mineral is not of secondary origin.

In his "Contribution à l'étude des gneiss à pyroxène et des roches à wernérite,"[1] Lacroix has figured and described some interesting occurrences of isomorphous growths of epidote and allanite in the amphibolic gneiss of Geffren-en-Roscoff. They are considered analogous to the Ilchester examples, with which he compared them. These growths are also reported from certain rocks of Finistère, France, the Niederösterreiches Waldviertel, and Oedegaaroden, Norway. The epidote in all these instances may be regarded as primary (p. 353).

Brögger[2] has lately called special attention to allanite-epidote intergrowths in certain pegmatitic dikes in Arendal, Norway. While Brögger is disposed to regard a part of the crystals as primary, he is also of the opinion that some of them are pseudomorphic in their origin.

In a late bulletin of the Geological Society of America, Keyes[3] has treated of "Epidote as a primary component of eruptive rocks." Special mention is made of the epidote found in the granites of the Patapsco Valley west of Baltimore.

Still more recently Hobbs[4] has noted some "New occurrences of parallel intergrowths of the minerals allanite and epidote." In referring to the latter mineral in the Maryland granites, Hobbs concludes that the evidence now at hand is sufficient to show that in some cases, at least, the epidote of the allanite-epidote intergrowths is original.

The association of allanite and epidote in the granites of Maryland is so intimate that there can be little doubt that both minerals were formed under the same physical conditions. In attempting to determine whether these minerals are of primary or secondary origin in the granitic rocks of Maryland, the evidence must necessarily be based in great measure upon the observed association with the other minerals. Allanite, as has already been stated, is comparatively easily fusible, and on this account it had long been quoted as one of the leading proofs against the igneous origin of granite. But its occurrence in such rocks as unaltered porphyrite, quartz-porphyry, dacite, andesite, and rhyolite—masses whose eruptive nature is not to be questioned, as shown by Iddings and Cross[5]—proves conclusively that this mineral actually does form in a molten magma. With allanite crystallizing out in liquid rock, there can certainly be no valid physical objection to the possibility of a similar crystallization of a species so closely related mineralogically and often so intimately associated.

Furthermore, the epidote occurs included in well-defined crystals of sphene, whose primary character can not be doubted (Pl. XL, fig. 2). Besides, it is not uncommon to find sharply defined crystals completely

[1] Bull. Soc. min. de France, t. XII, p. 139, 1889.
[2] Zeitsch. für. Kryst., Bd. XVI, p. 99, 1890.
[3] Bull. Geol Soc. America, Vol. VI, pp. 305-312, 1893.
[4] American Geologist, Vol. XII, pp. 218, 219, 1893.
[5] Am. Jour. Sci. (3), Vol. XXX, p. 108, 1885.

mantled by biotite, along with similar inclusions of zircon, apatite, and magnetite. There is a further evidence pointing toward the original character of the epidote in the occurrence of broken crystals of allanite-epidote intergrowths, into the open fractures of which biotite has formed (Pl. XL, fig. 1). To all appearances these fractures are protoclastic in nature. Finally, crystals of epidote, or isomorphous growths of epidote and allanite, with the crystallographic planes well defined, are found giving shape to the unaltered feldspars, quartz, and mica.

The inference is that both allanite and epidote form primary constituents in some, at least, of the Maryland granites.

The preceding remarks on epidote apply entirely to those formations regarded as primary. There are, besides, at least two other ways in which this mineral may be formed in eruptive masses—through contact metamorphism of calcareous rocks and through shearing. The first of these is shown in the lime-silicate-hornstones, where limestone fragments have been included in the molten granite. In these cases the epidote often makes up the greater portion of the rock. The alteration of granite is also a source of much epidote. It is then derived from the breaking down of the feldspar, along with various bisilicates. These occurrences require no further consideration here.

Briefly stated, then, it is believed that in certain of the Maryland granites the mineral epidote has originated in three different and distinct ways: (1) From primary crystallization, from a molten magma; (2) from metamorphic action, either through (*a*) contact of erupted rocks with calcareous masses, or (*b*) as the result of regional changes, and (3) through the secondary alteration of different components of igneous rocks. Epidote formed in any two or all three of the ways just mentioned may occur in the same hand specimens. In cases of this kind it would probably not be possible to tell by which of the methods nine-tenths of the epidotic grains were formed. The descriptions given on previous pages, however, are all based upon material in which the occurrences are thought to have originated in a single way.

HORNBLENDE.

Bright-green hornblende occurs abundantly as an essential constituent in one of the granites near Garrett Park. As seen on fractured surfaces this mineral appears in dark grains, averaging 2 to 3 mm in size, though frequently attaining measurements of 6 to 8 mm. Usually particles occur in irregular clusters associated with flakes of black mica, the whole embedded in a white matrix of feldspar, with some quartz. The hornblende aggregates are readily discernible on account of their satin-like luster. Crystals showing the bounding planes are rarely observed. Under the microscope this constituent is seen mixed with biotite in confused masses. The cleavage cracks are very pronounced, the basal sections giving the usual prismatic intersections of about 124°. Extinction angle against the cleavage plane, nearly 13°. The pleochroism is very marked.

Fig. 1.

Fig. 2.

THIN SECTIONS OF MARYLAND GRANITE.

PLAGIOCLASE.

The plagioclase is somewhat sparingly distributed, and usually is more or less decomposed, epidote and muscovite being commonly recognizable among its alteration products. Under the microscope this feldspar is distinguished from others by its polysynthetic twinning and by its greater tendency toward decomposition. Even where the twinning lamellæ are not visible the presence of secondary muscovite flakes quickly betrays the true nature of the feldspar and indicates at the same time its alkaline (oligoclase) character. Crystallographic boundaries are seldom met with, and zonal structure is likewise infrequent.

ORTHOCLASE.

The potash feldspar usually appears in allotriomorphic grains. The characteristic bounding planes, however, are not infrequently quite distinct; while in the porphyritic facies of the rock, crystals with the common faces fully developed are abundant. As a rule the grains are tolerably clear, indicating but slight tendencies toward decomposition.

Scattered through most of the granite rocks are numerous large grains showing micropegmatitic intergrowths of quartz and feldspar. They are usually rounded through magmatic corrosion, and occasionally show characteristic embayments.

MICROCLINE.

One of the most striking features of the granites under consideration is the prevalance of feldspar grains showing under the microscope the rectangular grating so characteristic of microcline, and commonly ascribed to the polysynthetic twinning according to the pericline and albite laws.[1] The twinning lamellæ, however, seldom have perfectly parallel sides, but thin out at one end, becoming greatly attenuated or replaced by other bars. It is very noticeable, also, that the lamellæ are much finer and very much more numerous in the immediate vicinity of cracks and along lines which seem to be microscopic planes of fracture, though the separation of two contiguous parts can not always be made out satisfactorily. In cases where small inclusions of other minerals appear in the feldspar crystal the lamellæ are much finer and extremely close together in two diametrically opposite directions from the foreign particle. These patches, more or less oblong in shape, with nearly parallel sides, have a width about equal to, and a length considerably in excess of, the diameter of the inclusion. In each longitudinal direction from the particle they fade out completely into the less twinned or clear portions of feldspar. In many large crystals of feldspar the twinning lamellæ are very numerous and well defined in one portion, but in other parts quickly disappear altogether and the untwinned area is indistinguishable optically from orthoclase.

[1] P. Sabersky: Neues Jahrbuch, BB. VII, p. 367.

The great abundance of cross-hatched feldspar in all the granites of Maryland—rocks which manifestly have been subjected to more or less intense dynamic influences due to orographic movements—strongly points to the conclusion that the microclinic structure may have been secondarily acquired. Von Rinne[1] has recently called attention to similar appearances in the cases of certain granites from the vicinity of Stockholm and of gneisses from Rothenburg, near Kyffhauser. In the gneissic rocks, which had been greatly pressed, the phenomena of the grating structure was more noticeable along lines of fracture, and when the partings were not apparent they were regarded as submicroscopic.

In some dike granites of Leutmannsdorf unusually fresh feldspars have been found by Beutell[2] having the microclinic patches developed in orthoclase crystals. These crystals are traversed by long albite streaks having an approximate trend in the direction of the vertical axis.

Sauer and Ussing[3] have also made special allusion to like phenomena in certain microclines in the pegmatites of Gasern, below Meissen (granulites and amphibole granites). The feldspars were not readily distinguishable from orthoclase, but along marginal zones and in patches characteristic cross-hatching was developed. These writers are inclined to believe that the homogeneous portions of the crystals are composed of extremely fine, submicroscopic, twinning lamellæ, which are not perceptible with ordinary magnifying powers. This is the view which was advanced by Michel-Lévy some years previous, in explanation of the same phenomena elsewhere. There is another class of lamellæ observable in the pegmatitic microclines of Gasern. All are extremely fine and give a striated appearance to certain portions of the field. These peculiar appearances suggest that they are due to gliding caused by pressure. They do not appear in the neighborhood of the larger albite streaks, since here the pressure was relieved by fracture.

In microcline from Langesundfjords, in southern Norway, Brögger[4] has also found in many cases that the mineral can not be distinguished by the grating structure, once thought to be so reliable a criterion. Chemical tests and careful determinations of the extinction angle were the only final means of identification.

QUARTZ.

Little need be said concerning the leading constituent of the Maryland granites, for it is essentially the same as in most other typical rocks of this nature. In all the granites within the limits of the region under consideration the quartz occurs in small or medium-sized irregular grains, though occasionally hypidiomorphic individuals are met with showing the crystal boundaries of R or ∞ R. As already men-

[1] Neues Jahrbuch, Band II, pp. 66–70, 1890.
[2] Zeitsch. f. Kryst., Band VIII, p. 373.
[3] Zeitsch. f. Kryst., Band XVIII, p. 196, 1891.
[4] Zeitsch. f. Kryst., Band XVI, p. 561, 1890.

tioned, nearly all the granite masses of the State have been subjected to more or less intense orographic pressure, and consequently the quartzes exhibit under the microscope undulatory extinction, and often a peripheral granulation.

GARNET.

Along the contact zones of inclusions, as at Sykesville, small, bright-red garnets are abundant. They are usually in rhombic dodecahedrons, with bright, crystallographic faces. In thin sections the crystals are transparent, with a slight reddish tinge, and possess the ordinary optical characters of the garnets.

TOURMALINE.

Tourmaline in the Maryland granite has thus far been observed only at Sykesville. There it occurs in or near the narrow contact zones of certain inclusions, but not abundantly. The crystals usually are long, quite small, rarely forming aggregates. When the crystalline contours are developed they show commonly the prismatic faces, seldom their terminal planes. The color is violet or purple in ordinary light, with strong pleochroism. Cleavage cracks are not noticeable.

PYRITE.

Pyrite appears in very minute quantities in the granites, but is difficult to detect in fresh rock specimens. In weathered granite it seems to be changed more or less completely to limonite.

PLEONASTE.

In a very few places in the Ellicott porphyritic granite there have been noticed small quadratic crystals of a dark-green mineral. In the very high index of refraction, in possessing no perceptible cleavage, and in other physical characters it appears to be one of the green spinels.

RIPIDOLITE.

In the weathered portion of the granites chloritic minerals are abundant. Manifestly they are decomposition products of biotite. Often one portion of a flake of black mica is chlorite; or it may be chloritized around the margin. In thin slices this mineral appears as clear plates, which are commonly fringed at the ends; parallel cleavage lines are distinct in transverse sections; refractive index low; pleochroism quite marked. In converged light a rather poorly defined cross is given, which careful observation seems to indicate is really a hyperbolic figure.

LIMONITE.

Limonite occurs sparingly, and then only in weathered portions of the granite, as an alteration product of pyrite and magnetite. It appears in all stages from a thin coating on crystals of these minerals to a complete replacement.

CALCITE.

Calcite is an unimportant constituent of the granite, occurring only as a decomposition product.

ROCK TYPES.

The granites of Maryland are divisible into four leading types: binary, or "true" granite; biotite granite, or granitite; allanite-epidote granite; and hornblende granite. Structurally there are three rather well-marked phases: granitic, porphyritic, and felsitic; with two sub-varieties: graphic granite and pegmatite.

The structure of granite is of course dependent largely upon the physical conditions under which the molten rock solidified. In general, the first-named structural variety is confined to the massive bosses, though it is possible that, inasmuch as the region is manifestly a mountainous district which has suffered enormous denudation, certain of the smaller granitic areas may represent old necks near the roots of early volcanoes. Such examples are not uncommon in Scotland. Long ago Jukes[1] called attention to the fact as a probable explanation of certain small granitic areas. Reyer,[2] Judd,[3] Geikie,[4] and others have have also referred to the same thing.

The porphyritic phases are quite limited in extent and are merely local facies of the larger masses, the groundmass being fully as coarse-grained as the typical granite. Fine-grained granite and also typical felsite occur in sharply defined dikes in a number of places. For the most part they may be regarded as apophyses of some of the larger bosses. The pegmatite may represent segregation veins in some cases, but in other instances they are certainly eruptive intrusions. Graphic granite in narrow veins is found in a few localities.

The more salient characters of the different mineralogical constituents have already been described. It remains now to consider briefly the associations of the various components in the several rock types as found in the different areas.

BINARY GRANITE.

Binary granite is a term here used to designate those granites which contain as essential components both white and black micas, in addition to the usual quartz and feldspathic ingredients. They are more commonly called, especially in Germany, "true" granites. Thus far only a single example of this rock has been recognized in Maryland and the adjoining States. This is the Guilford area, in Howard County, where the rock is light-colored and has a somewhat finer grain than most of the granites of the State.

---

[1] Manual of Geology, 2d ed., p. 93.
[2] Jahrb. k. k. geol. Reichsanstalt, Band XXIX, p. 405, 1879.
[3] Quart. Jour. Geol. Soc., London, Vol. XXX, p. 220, 1874.
[4] Trans. Geol. Soc., Edinburgh, Vol. II, p. 301.

Macroscopically the principal constituent, quartz, appears in clear, irregular grains, intimately intermingled with larger crystals of feldspar and small biotite plates. Scattered through the mass are also numerous flakes of white mica.

Under the microscope the rock seems to have been the least affected by pressure of any of the Maryland granites, the undulatory extinction, so apparent in certain constituents of most of the granitic rocks in the region under consideration, being much less noticeable than in any other type here mentioned. The quartz seldom shows its crystal boundaries, though occasionally the terminal planes of the unit rhombohedron (R) can be made out, and less frequently the prismatic outlines (∞ R). Liquid inclusions are very small and not very abundant.

The feldspars are tolerably clear, and show but slight tendencies toward kaolinization. Orthoclase occurs in large grains, usually with small inclusions of other minerals, while small micropegmatitic intergrowths of feldspar and quartz, showing magmatic corrosion, are not uncommon. Microclinic cross-hatching has begun to develop in some crystals, and is probably due to the same forces which have commenced to optically disturb the quartzes. The crystal boundaries are often well shown, the three pinacoids OP, ∞ P, and $\infty P\breve{\infty}$ and the orthodome $P\bar{\infty}$ occurring most frequently.

The plagioclase feldspars are not abundant. Oligoclase occurs in small grains scattered sparingly through the rock, and its presence is commonly indicated by the narrowly banded structure of certain feldspathic areas. The crystals are often hypidiomorphic, OP, $P\bar{\infty}$, $\infty P\breve{\infty}$, and ∞ P being the planes observed. Not infrequently small plagioclastic masses are included in orthoclase.

Biotite is not a prominent constituent, and consequently the granite is very light colored. Under the microscope it appears rather sparingly in small flakes. For the most part it is perfectly fresh, rarely showing the least signs of bleaching or of changing to other products.

Muscovite is very abundant in the Guilford granites. Aside from a few small, obscure needles occasionally developed in the interior of plagioclase crystals in the initial stages of breaking down, the white mica appears in large, clear flakes, sharply outlined, and usually intimately associated with the feldspar and biotite. With the dark mica it also forms parallel growths, often penetrating the biotite at various angles. In the isomorphic growths the two minerals are sharply contrasted. Sections cut perpendicular to the basal plane (OP) exhibit the biotite strongly pleochroic, from dark-brown to opaque, united to the clear muscovite plates in straight, sharp lines. In other cases the flakes interlock and the cleavage planes of the two micas stand at nearly right angles to each other. Frequently a sharply bounded muscovite plate is almost completely enveloped by the biotite. Equally sharply defined are the muscovite flakes against the feldspar grains.

The evidence at hand strongly indicates that in the Guilford granite a primary white mica or muscovite is present, contemporaneous in crystallization with the associated dark micas, or perhaps even somewhat older than the latter. The occurrence of muscovite as an original component of eruptive rocks has been seriously questioned, but the subject need not be entered into at length in this place, as it has been already discussed. Suffice it to say that to all appearances the two micas of the Guilford granite seem to have crystallized at nearly the same time.

The other constituents observed are occasionally small zircons and apatites.

A chemical analysis of the rock, showing its very acid character, by Mr. W. F. Hillebrand, of the U. S. Geological Survey, is as follows:

SiO_2	72.57	K_2O	4.33
Al_2O_3	15.11	Na_2O	3.92
FeO	.59	Li_2O	Trace.
Fe_2O_3	1.02	H_2O	.47
CaO	1.65		
MgO	.30	Total	99.96

GRANITITE.

The prevailing type among the granitic rocks of Maryland is that phase which is ordinarily termed granitite—a granular aggregate consisting essentially of quartz, feldspar, and biotite. This rock presents several interesting mineralogical facies in different localities. In a number of places tendencies toward porphyritic structure are quite manifest. Chief among the areas where the typical biotite granites are developed may be mentioned Sykesville, Relay Station, Texas, Halpin, and Havre de Grace, while the granitic rocks of Woodstock, Dorsey Run Station, Ellicott City, and Ilchester contain in addition a certain amount of epidotic minerals. These rocks vary considerably in color, from very dark iron-gray to nearly white, according to the percentage of ferro-magnesian silicates.

Under the microscope thin sections show plainly that the incipient stages of dynamic metamorphism have begun, and the cataclastic structure, so characteristic of massive crystalline rocks in mountainous regions, is quite apparent in many instances. The earliest differentiated constituents, zircon and apatite, are not abundant. Magnetite in minute octahedrons is often quite common, but is not usually met with in thin sections; panning, however, reveals this mineral in considerable quantities. The quartz is allotriomorphic, intimately interlocked with the feldspar grains. It rarely exhibits its crystallographic boundaries, is tolerably free from inclusions of other minerals, and contains comparatively few gas or fluid bubbles. The latter are commonly arranged in long rows, often traversing the entire field of the microscope. The disturbance of the optical homogeneity is quite considerable, for undulatory extinction is very decided in the majority of cases; yet usually the process has not gone far enough to cause much fracturing in the individual grains. Polysomatic crystals, however, are not of infrequent occurrence in certain areas.

The feldspar shows, both in the orthoclase and the plagioclase, evidence of incipient alteration, and in many cases decomposition is well advanced. Peripheral granulation is quite apparent in many instances, becoming more and more marked as the granite assumes more and more a gneissose structure.

The phenomenon is essentially identical with that stage of micro-structural metamorphism which Törnebohm[1] likened to masonry effects (Mörtelstructur), and to which Kjerulf[2] has more recently applied the term "cataclastic."

Many of the rounded and corroded micropegmatitic grains are also fractured; sometimes directly across the field, sometimes peripherally.

ALLANITE-EPIDOTE GRANITE.

The granites of some of the Port Deposit localities, of Woodstock, Dorsey Run Station, Ellicott City, and Ilchester, have recently been found to contain a considerable amount of epidote and allanite as important characteristic constituents. As already stated, the occurrence of these two minerals in the Maryland acid rocks was first noted by Hobbs, who had under consideration the porphyritic granites of the last two localities just mentioned. In the published notes particular attention is called to the isomorphous intergrowths of the epidote and allanite. Since the appearance of the paper alluded to, considerable additional material has been examined, from both the Ilchester and Ellicott City districts, and also from several other places.

In all their general characters the allanite-epidote-bearing granites are essentially identical with the granitites of the region, except as a rule they are somewhat more basic and consequently darker in color. The essential constituents show no noteworthy differences from the acid components of the typical biotite granites.

HORNBLENDE GRANITE.

Several occurrences of this type are known in Maryland, one of the most interesting being a short distance north of Garrett Park, on the Metropolitan Branch of the Baltimore and Ohio Railroad. Attention was called to this rock a short time ago, during the construction of a geological section along that line from Washington to Point of Rocks.[3] In hand specimens the rock is quite dark in color, though on a close examination the ferro-magnesian constituents contrast sharply with the alkali silicates. In thin slices the dark-colored minerals are found to be hornblende and biotite in about equal proportions and in confused aggregates. The biotite for the most part is tolerably fresh, with numerous inclusions of magnetite in minute crystals. The hornblende shows the incipient stages of breaking down, chlorite and iron hydroxide

[1] Neues Jahrb., 1881, II, Ref., p. 51.
[2] Neues Jahrb., 1886, II, Ref., p. 244.
[3] Bull. Geol. Soc. America, Vol. II, p. 321, 1891.

being present in small amounts in some parts of the different hornblendic masses. Both the monoclinic and triclinic feldspars are considerably decomposed, the alteration to epidote and muscovite being much more marked in the central portions of the grains than toward the margins.

From a purely petrographical examination of the rock it might pass for a quartz-diorite, but the association of the mass with the other granites of the immediate vicinity seems to indicate that it is actually a dioritic facies of a hornblende granite.

CHAPTER IV.

THE GRANITE EXPOSURES IN CENTRAL MARYLAND.

As stated in another place, a somewhat independent treatment is required for each of the several granitic areas. The various bodies differ greatly in the importance of their bearing on the geological history of the granitic masses of Maryland. The natural outcrops along the streams and exposed uplands are numerous, but do not afford as satisfactory opportunity for detailed study as might be expected. Fortunately, extensive quarries, railroad cuttings, and other artificial openings supply in a great measure the supplementary information needed. For the geographical distribution of the areas of Maryland granite here considered, see map (Pl. XXXVI).

TEXAS AREA.

This area comprises an oval, boss-like mass, between 4 and 5 square miles in superficial extent. It lies almost entirely within the marble district of Cockeysville, though on the north it comes in contact with gneiss, a thin band of the latter also running down on the eastern margin. On the southwest a narrow strip of quartzite borders it. This granite area is well marked topographically, forming an elevation which rises more than 250 feet above the surrounding valleys, and is cut on all sides by short, steep-sided ravines. The interior of the district is flattened, and forms a well-defined, though miniature plateau. This rounded prominence owes its peculiar physiognomy almost entirely to erosion. The surrounding rocks being more easily affected by the ordinary atmospheric agencies have been removed much more rapidly than the hard central granitic boss, and, as they dip away from the central mass, their upturned edges are more readily attacked than they otherwise might have been.

The rock is an ordinary biotite granite, with a porphyritic facies along the western margin of the area. The mass has manifestly been greatly squeezed, giving it a distinct gneissoid appearance. For this reason the porphyritic portions may now be properly called "augen-gneiss."

In thin sections under the microscope the quartzes exhibit undulatory extinction, the crystals being often badly broken. The feldspars present no noteworthy phenomena. In both the plagioclase and orthoclase small muscovite plates have developed. Zircons are rather abundant.

WINDSOR ROAD OUTCROPS.

These outcrops appear a short distance west of Baltimore, near where the Windsor road crosses Gwynns Falls. The area is a small one, less than half a mile in width in the widest place, and extends from Highland Park southwestward a distance of about one mile. It is almost entirely surrounded by gabbro and hornblende-gneiss.

The rock is a dark-gray granite, somewhat gneissoid in places, showing that it has been considerably pressed. It has been quarried somewhat, and forms a very durable building stone.

Under the microscope the granite shows plainly the effects of great pressure upon the individual constituents. Many of the quartzes have become polysomatic, and the feldspars are also badly broken and rounded.

RELAY EXPOSURES.

A small granitic area is exposed in the vicinity of Relay Station, 9 miles southwest of Baltimore. The station itself is at the mouth of the Patapsco gorge and immediately at the foot of the Piedmont escarpment. The granite forms salients on either side of the deep and narrow gorge which rise to a height of more than 200 feet. The granite is also exposed in several adjoining ravines in the neighborhood. The rock is the common dark-gray, rather coarse-grained granitite, somewhat pressed and more or less distinctly porphyritic. Dikes of felsite occur near this area and probably represent apophyses of the chief mass.

In general microscopical characters this granite more closely approaches that of the Ellicott City district. Seen microscopically, thin slices of the rock disclosed large grains of all the essential constituents closely interlocking. The quartzes are considerably crushed, the individual grains being fractured, yet the separate parts still remaining in place. The feldspars, while quite irregular in outline for the most part, show very frequently their crystallographic boundaries. The phenocrysts almost always appear with well-defined planes. All the feldspathic constituents exhibit peripheral granulation very decidedly. They also show a strong tendency toward decomposition, with the development of muscovite. The biotite is changed to a greater or less extent, chlorite being abundantly developed. Magnetite is of frequent occurrence.

In the outcrops, which are best shown perhaps just west of the Relay Station, where the main stem of the Baltimore and Ohio Railroad cuts through a sharp salient, jointing is shown, but not prominently. Atmospheric decomposition of the rock has gone on profoundly, as is well shown at the same place.

GUILFORD OPENINGS.

This area is quite large, nearly equaling in size the largest in Maryland, very irregular in outline, and is bordered by gabbro on the east and by gneiss on the west. There is little or no evidence of squeezing. Everywhere it is the same rather fine-grained rock, showing no porphyritic facies nor dikes of finer material. Little has been done to utilize this granite. Being situated a considerable distance from railroads, facilities for transportation to market are very poor. Three small quarries have been opened near the creek where the old Guilford mill was once located, and here the best exposures are to be seen. The rock is very light-colored and contains abundant flakes of white mica. Microscopical examinations of thin sections would seem to indicate that the granite is of the true binary type, with muscovite forming an original constituent. A full petrographical description has been given on a previous page, under the head of "Binary granite," together with a complete chemical analysis.

ELLICOTT CITY REGION.

The Ellicott City granite area is an irregular, L-shaped mass having an extreme length of about 5 miles in an east and west direction and a breadth varying from a half mile to 2 miles. On the north, west, and south it is bordered by a large gabbro area; on the east, by gneiss. A considerable portion of the granitic area of this district is overlain by Neocene gravels (Lafayette formation) and Cretaceous clays (Potomac formation), thus concealing from direct observation much of the rock in question. The clastics, however, are quite thin, and consequently all the rivers and even the minor watercourses have cut their channels down to the crystallines. The boundaries of the granites, gabbros, and other massive rocks are thus capable of being determined with nearly as much accuracy as if the sedimentary deposits were not present.

The numerous outcrops of granite within the Ellicott City area need not be referred to in detail here. They occur in their best development along the gorge of the Patapsco River, but are also abundant on most of the smaller tributaries of this stream, as well as of the Little Patuxent, whose headwaters are in this region.

The rock of this district is, on the whole, a medium-grained granite, rich in epidote and allanite. In places toward the periphery of the area the granite assumes a distinct porphyritic facies. Here the feldspathic phenocrysts vary in size from more than 2 cm. in length down to such as are not clearly differentiated from the feldspars in the groundmass.

When examined microscopically, some portions of the granite show that they have been subjected to moderate orogenic pressure, while other parts appear practically to have escaped squeezing. The quartz occurs in allotriomorphic grains showing abundant gas bubbles. The biotite, in ordinary specimens taken from exposed ledges, shows a tendency toward bleaching and toward chloritization. In the same samples the plagioclase feldspars have begun to decompose, with a development of small, clouded, muscovite flakes. Granophyric intergrowths of orthoclase and quartz in rounded grains are of frequent occurrence. Allanite and epidote in large parallel growths are abundant even in the perfectly fresh rock. They have been described in detail in another place.

DORSEY RUN CUTTING.

The Dorsey Run area is a small oval district located on the Patapsco River, a few miles above Ellicott City. It is surrounded on all sides by a typical dark-colored gneiss. The exposure is one of the best in central Maryland for plainly exhibiting the relations of the granite to the included and associated gneisses. The gneiss, greatly contorted and puckered, is broken through by a massive granite. An excellent section has recently been made in straightening the main stem of the Baltimore and Ohio Railroad at the little station known as Dorsey Run. The cutting is nearly 400 feet in length and 40 to 50 feet in height. It is diagrammatically represented in Pl. XXXVII, fig. 3.

No. 1 is massive granite with abundant inclusions, fragments, and large blocks of dark-colored gneiss, manifestly derived from the general gneiss mass near by.

Nos. 2, 4, and 6 are composed of gneiss greatly puckered and somewhat contorted. It is penetrated by two dikes (Nos. 3 and 5) of very light-colored, fine-grained granite, which is shown by the chemical analyses given to be very much more acid than the typical granite of the district.

The massive granite to the right, Nos. 7 and 9, is the same as No. 1, and contains large masses and irregular blocks of the gneiss. Near the center of the exposure is a very large piece of gneiss greatly twisted. To all appearances the twisting of the gneiss has been due to movement in the granite when it was yet in a viscous state.

No. 10 is the puckered gneiss, again with small dikes, No. 11 running through it. Portions of probably the same part are scattered through the large neighboring granite mass No. 12. In No. 13 the gneiss is very much contorted, but otherwise it is in all respects similar to the other gneiss patches.

No. 14 is a massive, very coarse-grained pegmatite, as is also No. 16, while between lies a large massive granite (No. 15), with occasional gneiss inclusions.

Chemical analyses of the different parts of this section, by Mr. W. F. Hillebrand, give the following results:

	I.	II.	III.	IV.
SiO_2	62.91	70.45	57.33	48.92
Al_2O_3	19.13	15.98	15.31	16.57
Fe_2O_3	.98	.75	3.39	4.21
FeO	3.20	1.84	8.19	9.18
CaO	4 28	2.60	3.95	9.69
MgO	1.69	.77	4.36	5.98
K_2O	3.38	3.59	4.57	1.56
Na_2O	3.94	3.83	1.22	2.47
Li_2O	Trace.	Trace.	Trace.	Trace
H_2O	.63	.45	1.80	1 68
Total	100.14	100.26	100.12	100.26

I is the typical granite, taken from selected, average specimens of the large granite masses (Nos. 1, 7, 9, and 15 of the section).

II is from the light-colored dikes, also selected specimens from different parts (Nos. 3, 5, and 11 of section).

III is from a large assortment of inclusions in the granite.

IV is the typical gneiss (Nos. 4, 6, 10, and 13 of section).

The massive granite of Dorsey Run is a dark-colored rock, tolerably even grained and quite homogeneous in texture. Allanite and epidote are abundant accessory constituents. As shown in the chemical analysis of the rock (I of the foregoing tabulation), the percentage of silica is rather low, while in the dike portion it is between 7 and 8 per cent higher. Comparisons with the analyses of other granites of the region show that the Dorsey Run intrusion is quite basic, the most acid apophyses being about the same in acidity as the typical masses at Woodstock, Ellicott City, Relay, and elsewhere.

The microscopic characters of the granites of Dorsey Run present no points worthy of special mention, and differ little from the other allanite-epidote granites of the region. The examination of chips taken from near the contact of the granite with the gneiss shows a very perceptible change in the grain of the rock. The light-colored dikes, which are probably apophyses of the large mass, are likewise much finer grained than the more massive portion. On the whole the granite appears to be much less profoundly decomposed than the rocks in the granitic areas immediately to the west.

WOODSTOCK QUARRIES.

GEOLOGICAL RELATIONS.

The Woodstock granite forms a small isolated patch midway between the two largest granitic masses of the region. Though having a superficial extent of scarcely 2 square miles, it is economically one of the most important areas in Maryland. Extensive quarries have been opened in several low hills a couple of miles from the Patapsco and a short distance from the station of Woodstock, on the main line of the Baltimore and Ohio Railroad. From a point a short distance below the station a long switch which crosses the river has been built to two of the openings, enabling the rock to be loaded directly upon the cars for transportation. The granitic mass of Woodstock is surrounded on all sides by the characteristic Piedmont gneiss. In hand specimens the two rocks are sharply contrasted, though in the field their exact lines of contact are largely obliterated by atmospheric decay.

The granite is rather light-colored, uniformly fine-grained, and massive. No dikes of any kind are seen in connection with it.

INCLUSIONS.

The inclusions of rocks in the Woodstock granites are not less striking than those in the Sykesville district, and in many respects they are more interesting. They are chiefly of gneiss, and occur often in huge, irregular blocks 6 to 8 or even 10 feet in size. Some of the included masses are beautifully puckered and wrinkled. Being much richer in ferro-magnesian silicates than the granite itself, their irregular outlines contrast sharply with the light background. (See fig. 26 and Pl. XLI.) These inclusions furnish further evidence of the eruptive nature of the granite. The contact phenomena are essentially the same as in the Sykesville examples of gneissic inclusions, described fully further on; and the marginal metamorphosed zone is, as in those cases, quite narrow.

JOINTING.

Nowhere among the Maryland granites is the phenomenon of jointing better shown than in the Waltersville quarry of the Woodstock area. (See Pl. XLII.) The horizontal divisional planes are particularly prominent, and at first glance give the impression of true stratification.

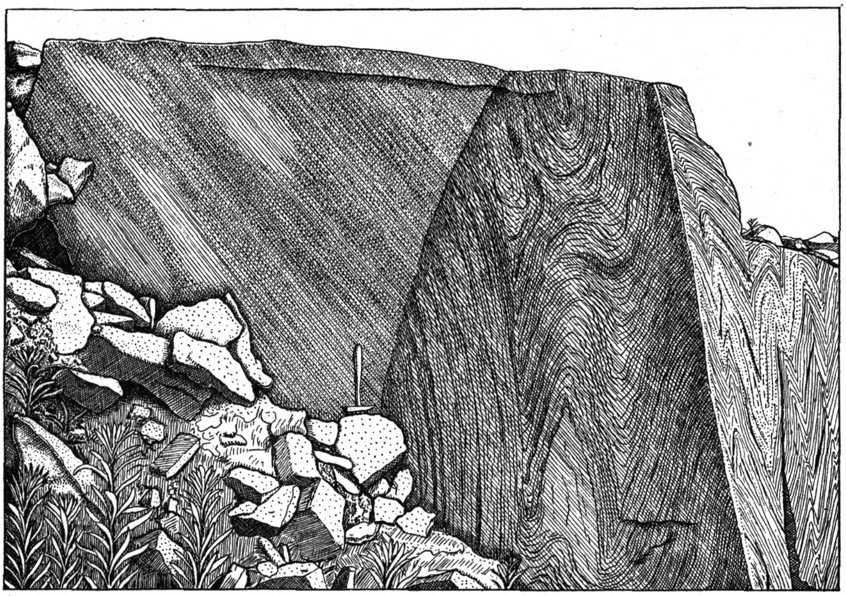
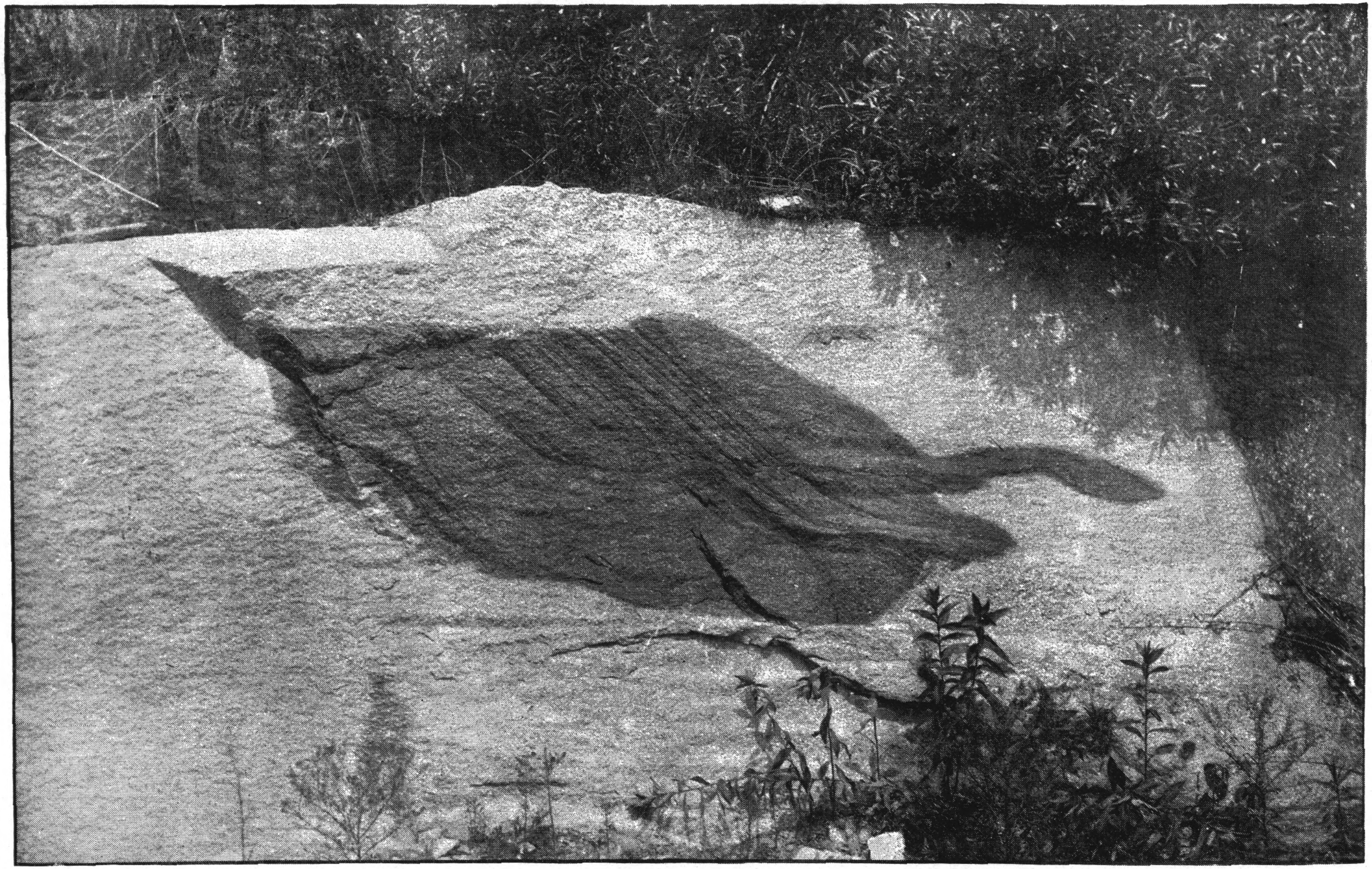


FIG. 26.—Gneiss inclusion in granite, Woodstock, Md.

These principal joints extend for considerable distances. They are crossed by numerous inclined and vertical planes of natural cleavage, which are usually much less prominent than the major lines just alluded to.

As to the origin of the joints, it seems probable that they are due to two causes—in part to the contraction of the granite during its original cooling, in part to subjection to severe tortion. The latter force is in all probability in action at the present time; for, as already stated, it would seem that, according to McGee,[1] crustal movement is now in active operation in the Piedmont region. The optical disturbances of

[1] Seventh Ann. Rept. U. S. Geol. Survey, p. 619, 1889.



GNEISS INCLUSION IN GRANITE; WALTERSVILLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND.

the granitic quartzes of the district may also be due in some degree to the same cause, and the very marked rifting also points to the same conclusion. That systematic jointing may actually arise from strains of this kind has been satisfactorily proven experimentally by Daubrée,[1] and seems to find full confirmation in other extensive trials, as well as in the field.

WEATHERING.

In approaching the middle one of three quarries in the Woodstock district, fine illustrations of the weathering of granite are encountered. The quarry ledge has the appearance of a great wall of cyclopean masonry, layer upon layer of huge blocks rising one upon another with the regularity and precision of human workmanship. (See Pl. XLIII, and a nearer view of same in Pl. XLIV.) The separate blocks are more or less oblong in shape, and often measure 15 to 20 feet in length and from 2 to 8 feet in height. They are all more or less rounded, the spaces between the different bowlders being filled with incoherent granitic sand, derived from the decomposed edges and the sides of the blocks. It is quite evident that the granitic mass was originally everywhere jointed, and that atmospheric decay took place much faster on the edges and corners than on the flat sides of the great fragments, thus quickly rounding and forming them into bowlders like those found throughout drift areas. (See Pl. XLV.) The sandy matrix is usually from 5 to 10 inches in thickness. The interior of the bowlders is perfectly fresh, and affords the best of rock for building purposes. (See Pl. XLIV.) As decomposition progresses the amount of interstitial sand greatly increases, and the blocks become proportionately smaller.

The different stages of granite disintegration are seen in (1) Pl. XLII, (2) Pl. XLIII, and (3) Pl. XLV, in which is shown a large bowlder 10 feet in diameter separated from the surrounding material. Pl. XLIV shows an enlarged view of Pl. XLIII, the bowlders being cut in two, disclosing the interiors perfectly fresh and as compact as the rock from the other quarries.

Another interesting phase of rock decay shown in the same opening is the spherical parting of the bowlders of disintegration. These bowlders consist peripherally of thick concentric shells, which come off one after another, not very unlike the different coats of an onion. (See Pl. XLVI and Pl. XLVII.)

The extreme difficulty with which the Woodstock granite yields to the attacks of frost, moisture, and other meteoric influences indicates that the rock is well adapted to resist disintegration through the usual exposure to the weather. Under ordinary circumstances chemical changes are but slight, and the cohesion of the components is sufficiently great to make this stone perhaps the most durable of any in the State.

---

[1] Études syn. de géol. exper., p. 300, 1879.

SYKESVILLE AREA.

GENERAL RELATIONS.

The granitic area of Sykesville is the most westerly of the acid eruptives within the limits of the Piedmont zone in Maryland. (See Pl. XXXVII, fig. 2, for general geological relations; also see fig 27.) At the same time it is one of the largest single masses of granite exposed in the crystalline belt of the central part of the State. It is irregularly circular in outline, with apparently several broad prolongations running to the southward. Traversing the area in a west-to-east direction is the Patapsco River, flowing rapidly down its rock-cut channel; while near the center of the mass and overlooking the river is the little village from which the granite takes its name. A casual observation of the exposed, weathered surfaces of the rock might easily lead to the mistake of supposing it in many places to be gneiss. But, although considerably

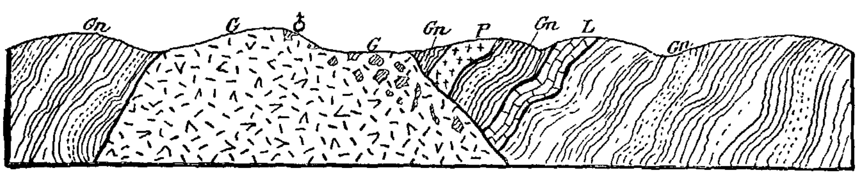


FIG. 27.—Ideal section of the Sykesville granite area.

squeezed, it still retains its undoubted granitic character at depths beyond the immediate influences of subaerial decay. The natural outcrops of the rock are numerous along the smaller tributaries of the chief watercourse. The freshest examples of these are found at the schoolhouse, 4 miles directly south of Sykesville. The best exposure in the district, however, is beside the railroad, a few hundred rods below the station, where a quarry has been recently opened for paving-blocks. During the progress of the work large numbers of inclusions of foreign rocks were brought to light in the granite, furnishing a good proof of its eruptive origin. These inclusions consist of irregular fragments of all sizes and shapes. Among the various fragments noted may be mentioned those which were originally limestone, soapstone, pyroxenite, vein-quartz, hornblendic and biotitic gneisses. Both with the naked eye and in thin slices under the microscope contact phenomena are seen similar in all respects to those which characterize the action of intrusive igneous rocks on calcareous or argillaceous sediments through which they have broken or which they inclose.

LIMESTONE INCLUSIONS.

The inclusions derived from the limestone appear as thin, yellow slabs, from one to several centimeters in thickness and of various sizes. One of these in particular requires special notice. It is a very thin plate, perhaps a foot across, which has been twisted and bent into a

VIEW OF WALTERSVILLE QUARRY, NEAR WOODSTOCK, MARYLAND, SHOWING VERTICAL AND HORIZONTAL SYSTEMS OF JOINTING.

CONCENTRIC SHELLS OF GRANITE, MIDDLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND.

most fantastical shape. (See Pl. XLVIII.) It may originally have been flat, and became twisted after being inclosed in the liquid magma, or it may have been a fragment of the rock puckered considerably before being broken away from the main deposit. Four distinct zones are readily recognized macroscopically in the inclusions of this class: (1) The median portion, which is fine-grained and lemon-yellow in color. It is surrounded by (2) a narrow band, usually 2 to 3 mm. in thickness, white in color, and apparently composed chiefly of minute grains of quartz. Then comes (3) a very fine-grained, dark-colored shell of varying thickness, containing abundant small garnets, up to 1 mm. in diameter. In many cases this layer is so thin as to be scarcely noticeable. It shades off rather abruptly into (4) the typical granite of the area.

Microscopically the four zones are even better differentiated.

(1) The yellowish, central part is made up almost entirely of very fine grains of epidote and quartz, in the proportion of about 2 to 1, a little chlorite also being present. In some sections considerable hornblende is developed. A chemical analysis of this lime-silicate-hornstone was made by Mr. W. F. Hillebrand as follows:

SiO_2	67.02	K_2O	.09
Al_2O_3	13.77	Na_2O	.66
Fe_2O_3	4.64	H_2O	1.16
Fe_2O	1.02		
CaO	11.09	Total	100.10
MgO	.65		

(2) The narrow white band is found to consist almost wholly of fine, allotriomorphic quartz, though a few large grains are noticed. Epidote in minute elongated crystals and in small, irregular, rounded grains is sparingly distributed through the layer; also, occasionally, little specks of biotite and very minute particles of magnetite. The boundaries of this zone are both sharply defined.

(3) The fine-grained dark zone, though apparently not well represented in some cases, has a thickness of more than 50 mm. in some parts of the S-shaped mass just alluded to. The quartz is very fine and makes up the greater portion of the mixture. Garnets in small, sharply defined dodecahedrons are numerous. Only small quantities of magnetite are observable. The epidote is abundant, in small elongated crystals preserving some of the crystallographic boundaries, but seldom the terminal planes. The irregular grains so common in the lime-silicate-hornstone area are rarely met with here. In the larger S-shaped mass this soon becomes feldspathic toward the exterior, though the orthoclase and plagioclase are greatly decomposed and muscovite is abundantly developed. The garnets are also much larger, often attaining a measurement of more than a millimeter.

The chemical composition, according to an analysis by Mr. W. F. Hillebrand, is:

SiO_2	47.35	K_2O	6.83
Al_2O_3	29.76	Na_2O	2.84
Fe_2O_3	2.94	Li_2O	Trace.
FeO	3.15	H_2O	3.15
CaO	2.20		
MgO	1.60	Total	99.82

In some of the inclusions small tourmalines are quite common in this zone.

SOAPSTONE INCLUSIONS.

The soapstone inclusions show little or no traces of contact metamorphism. Rhombohedrons and irregular grains of siderite abound in the talcose fragments. These fragments are identical in all observable characters with soapstone containing siderite, which occurs abundantly at Mineral Hill, 7 miles northeast of Sykesville, and which belongs to the long belt of this rock extending many miles across this region. This belt passes a short distance to the eastward of Sykesville.

GNEISS INCLUSIONS.

Biotitic and hornblendic gneiss fragments are abundantly distributed through the granite. The margins are usually changed considerably for a distance of about 1 cm. (fig. 28). The interior of the gneiss pieces is practically unmetamorphosed. It is much lighter in color than the

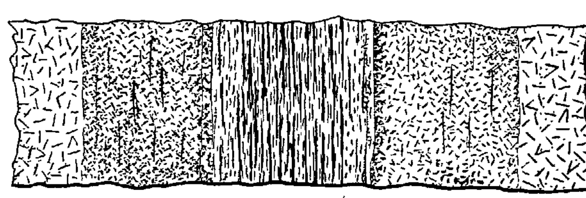


FIG. 28.—Section of small gneiss inclusion with metamorphosed edges in granite, Sykesville Md.

contact border. The constituents have undergone much crushing, and the feldspars are scarcely recognizable. The biotite is nearly all bleached, and chlorite is very abundant. Considerable secondary epidote and muscovite and a few large decomposed cubes of pyrite are also present.

The margins of the gneiss blocks are dark-colored and much finer in grain. No traces of pressure are observable, and apparently complete recrystallization has taken place. Biotite is very abundant in small flakes oriented in the direction of foliation. A little plagioclase and orthoclase and small quantities of pyrite occur.

OTHER INCLUSIONS.

A number of small, greenish fragments are seen under the microscope to be composed of biotite, chlorite, and hornblende, with some

FLATTENED CONCENTRIC SHELLS OF GRANITE, MIDDLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND.

quartz. They appear to have been originally derived from the pyroxenite belt associated with the soapstone zone just alluded to.

Large inclusions of vein-quartz are also met with.

In the present connection it may be well to state that inclusions and phenomena similar to those observed in the Sykesville area have been described recently by H. Credner.[1]

WEATHERING.

On the whole, weathering effects of the Sykesville granite present some striking contrasts with those of the Woodstock area, and are much more complete. Decomposition extends from the surface downward for 30 feet or more in places. The decayed portion preserves all the appearances of the granite itself, but under the touch it falls readily into sand. This loose arenaceous material is without bowlders or pebbles, is easily excavated to a depth of many feet, and when suitably exposed to the action of running water is carried away, as a sand bank along some watercourse melts into the flowing stream.

The absence of glacial action in Maryland has left many phases of rock decay not usually met with in the crystalline districts to the northward. In those areas where ice has acted vigorously in great masses the rocky surfaces are often smooth and hard, with little or no traces of internal disintegration. South of the terminal margin of the last great ice-sheet, as in the State just mentioned, it is not uncommon to find in granitic and gneissic areas the rocks broken down for many feet below the surface, the débris still remaining in situ. As has been shown by Russell,[2] the depth to which this kind of rock decay takes place appears to increase rapidly with distance southward from the glaciated region.

A dozen miles south of Sykesville and a few miles north of Sandy Spring, granitic rocks are exposed along the Big Patuxent and its tributaries. In its general character this rock appears to be essentially like the Sykesville granite. It was thought at one time that the area formed the southern extension of the Sykesville district, but the two masses are now known to be separated by a considerable interval occupied by the Piedmont gneiss.

GARRETT PARK OUTCROPS.

The granitic exposures alluded to here as belonging to the Garrett Park district embrace several small outcrops within a radius of a few miles of a new station, so named, on the Metropolitan Branch of the Baltimore and Ohio Railroad a few miles northeast of Washington, D. C. (See Pl. XXXVII, fig. 1, for general geological relations.) In the immediate vicinity of the village itself the chief exposures are along Rock Creek, a short distance northward.

[1] Erläuterungen zur geologischen Specialkarte des Königreichs Sachsen, Section Pillnitz, p. 17. 1892.
[2] Bull. U. S. Geol. Survey No. 52, 1889.

At these places several small quarries have been opened. The rocks have been considerably sheared, so that a decided schistose structure has been developed. Numerous irregular fragments and blocks of dark gneiss are embedded in places. A large face of one of the quarries, with numerous inclusions, is represented in fig. 29.

At Bethesda some large blocks of granite protrude through the soil in the fields along the Georgetown and Rockville road. They are typical granitites, and contain numerous garnets. Two miles southwest of Garrett Park, Rock Creek cuts its channel directly through a small granite area. On the south side, near the Rockville road, a large quarry has recently been set in operation. The granite is fine-grained, light-colored,

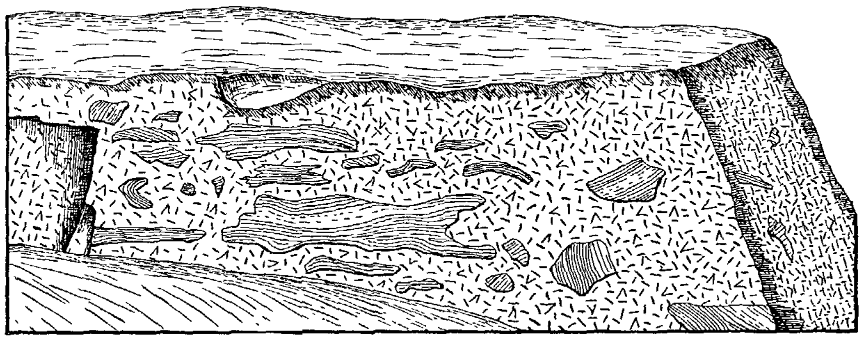
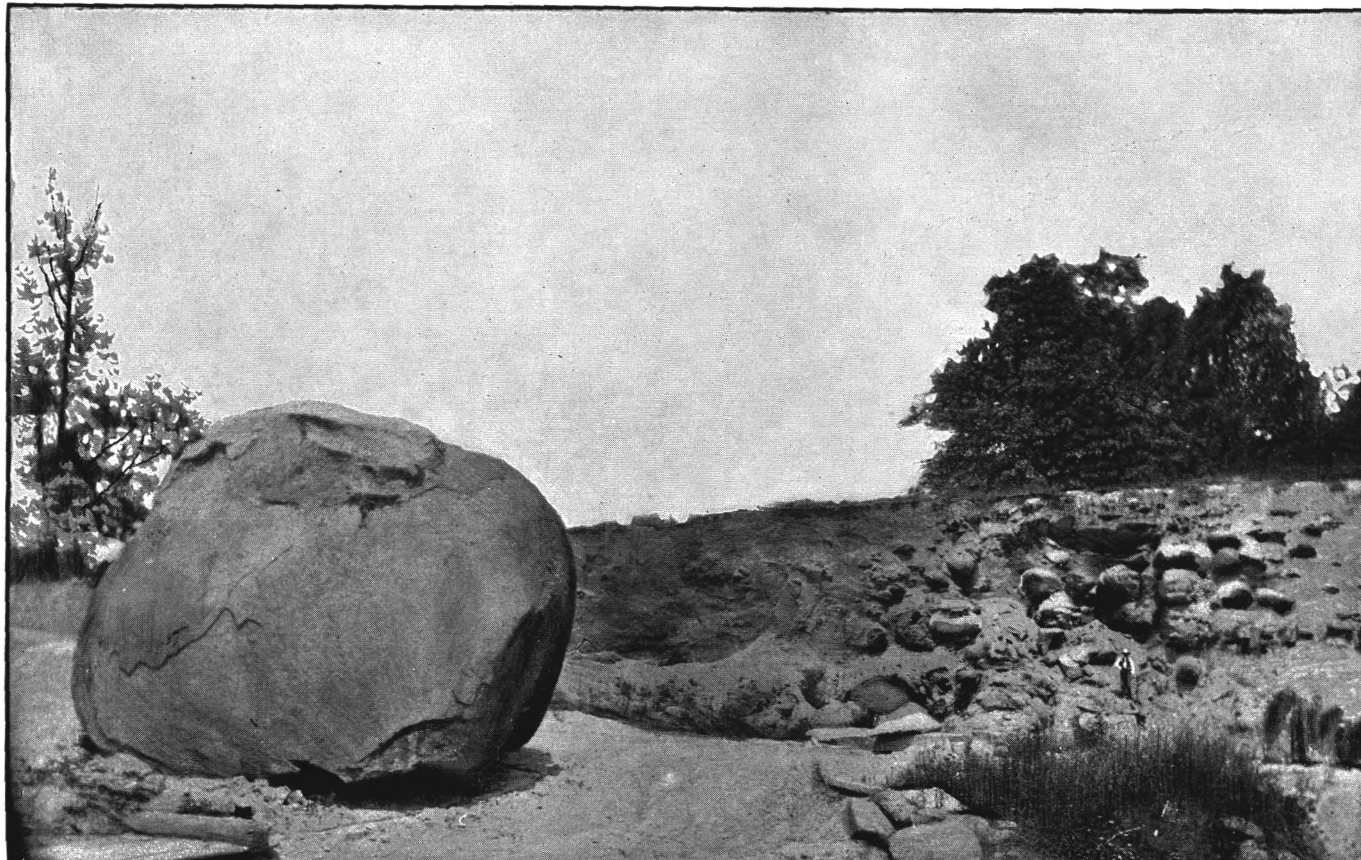


FIG. 29.—Face of quarry on Rock Creek, near Garrett Park, Md.

owing to the small percentage of ferro-magnesian silicates, and contains numerous basic secretions, lenticular in shape and of various sizes. It may be due to this segregation of the iron minerals that the rest of the mass is so poor in these constituents.

On the east the granite mass is bordered by a soapstone belt, the line of contact being well exposed. A short distance to the south a hill of pyroxenite seems to limit the granitic area in this direction. North of Garrett Park about 2 miles occurs the area of hornblende granite to which reference has already been made. It is exposed for more than half a mile along the road leading to Rockville. Large bowlder-like blocks lie scattered over the land in abundance, and several large outcrops are noticeable. The rock is rather dark in color, but the different constituents are well defined. There appear to be about equal amounts of both hornblende and biotite distributed through the granite.



VIEW OF MIDDLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND, SHOWING SPHERICAL WEATHERING OF GRANITE.

CHAPTER V.

ERUPTIVE ORIGIN OF CERTAIN MARYLAND GRANITES.

TWO THEORIES.

In the explanation of the origin of large granitic masses two opposed hypotheses have long found favor among geologists. According to the one, a granite is the last stage in the metamorphic alteration of mechanical sediments. According to the other, a granitic mass is the product of the gradual cooling of an acidic molten magma under pressure. In the first case it is claimed that all the gradations have been traced in the same mass, from undoubted clastics through slaty, schistose, and gneissic phases to the truly granitic types, so that one end of an originally sedimentary deposit may be now unaltered while the other is a truly crystalline rock. On the other hand, unquestionable eruptive granites are known to pass into gneiss, and even into schistose stages, through the agency of compression and shearing. Regarding the facts deduced in support of the first assumption, and without referring to any specific instances, it seems quite probable that in the majority of cases bearing directly upon this point, sufficient discrimination has not been exercised along the lines separating the semicrystalline from the holocrystalline areas.

EVIDENCE OF IGNEOUS ORIGIN.

Recently great stress has been laid on the metamorphosing influences of orographic movements in disguising the original character of rocks—making eruptives more and more like sedimentary deposits and clastic beds more and more like massives. Without entering into a discussion of the general subject, it is intended here merely to set forth some of the evidence which points to the eruptive origin of certain of the Maryland granites. That these particular rocks are really eruptive in character has been seriously questioned by some and denied by others.

The evidence that the granites in question are igneous in nature is deduced from several different and independent sources: (1) From field relations, (2) from inclusions, (3) from contact phenomena, and (4) from microscopical examinations.

(1) FIELD RELATIONS OF THE GRANITES.

As stated elsewhere, the eastern half of the Piedmont region consists chiefly of gneisses, broken through in numerous places by undoubted eruptives—as gabbro, diorite, and pyroxenite—until at present these rocks occupy fully one-half of the exposed surface of the district. Now, a careful tracing of the granites shows that they have cut indiscriminately across the igneous rocks mentioned, as well as the gneiss, passing uninterruptedly from one petrographically distinct mass to another. In other words, the acidic types of crystallines seem to be younger in age than the gabbros and the most basic rocks, as if they too had broken through all the other eruptives. Near some of the granite masses true granitic and felsitic dikes are clearly defined, which would ordinarily be regarded as apophyses of the main body, were the rock regarded as an eruptive. Furthermore, at Dorsey Run Station for instance, large exposures show the granite spreading widely apart enormous layers of twisted and puckered gneiss. At Woodstock huge blocks are completely inclosed in the granite.

As already remarked, the line of contact between the granite and the contiguous rock is seldom determinable exactly on account of profound superficial decay. Yet occasionally artificial excavation into the acid rock reveals clearly such contacts, as at the new quarry opened about 2 miles northwest of Garrett Park, where the line between the granite mass and the adjoining soapstone belt is very sharply defined.

(2) INCLUSIONS.

Perhaps one of the most conclusive proofs of the eruptive nature of some of the Maryland granites is the occurrence in the mass of large numbers of inclusions—fragments of foreign rocks, both sedimentary and eruptive. These have all been described more or less at length in the preceding pages, to which reference may be made for fuller details. At Sykesville, where they occur so abundantly, the irregular angular fragments and blocks of all sizes are identical with rocks of the neighborhood. In most of the cases the interior of the foreign pieces is scarcely altered at all, though the exterior consists of more or less completely metamorphosed shells of varying thickness. The Woodstock and Dorsey Run granites show similar phenomena equally as well, or even better. In both instances blocks of highly puckered gneiss are very prominent, and they all possess narrow marginal borders of dark, fine-grained, completely changed rock, which contrasts sharply with the light-colored surrounding granite. Certain outcrops near Garrett Park furnish good illustrations of the same kind, though here the granite has been squeezed considerably more than in the other cases mentioned. At this place there is one exposure showing numbers of small lenticular masses of a black color which might easily be taken for inclusions but for their regularly rounded outlines. These are doubtless basic secretions which developed in the acid magma.

(3) CONTACT PHENOMENA.

For reasons already explained, the contacts between the granitic masses and the adjoining rocks are rarely seen to advantage. The investigation of the contact zones has therefore been carried on largely with the inclusions. This has been very satisfactory on account of the

BOWLDERS OF DISINTEGRATION, IN PLACE, MIDDLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND.

variety of foreign rocks represented and the abundance of the fragments. In most of the fragments it is only the outside which is changed—to the depth of from 2 to 4 cm., or more—the interior still preserving the rock in its original character, so that no doubt arises concerning its composition and structure previous to its embedding in the granite. The contact zones are in all respects identical with the contact belts of other localities where acid eruptives have pushed up against the same kind of rocks.

Chemical analyses of the unaltered inclusions, the metamorphic shells, and the surrounding granites show that the altered shells have an acidity intermediate between the inclusions and the granites.

These proofs of eruptive origin of the Maryland granites are quite similar to those which Barrois[1] has formulated for the granites of Rostrenen.

(4) MICROSCOPICAL EXAMINATIONS.

Aside from the ordinary microscopical characters indicative of cooling from fusion, certain of the granites under consideration show some additional phenomena pointing to the same conclusion. These are large grains of micropegmatitic intergrowths of quartz and feldspar, rounded through magmatic corrosion apparently, and having the characteristic embayments so commonly associated with cases of this kind. The descriptions of the thin sections have already been given and need not be repeated here.

AGE OF THE MARYLAND GRANITES

The eruptive nature of certain of the Maryland granites being admitted, the question naturally arises as to the time of the eruptions As has been suggested, the region represents an old baseleveled mountain system which has been elevated perhaps many times and is at the present time again being eroded.

It has been stated that of the eruptives of the eastern Piedmont district all are older than the granites. But it is not at all probable that the different granitic masses mentioned were contemporaneous in appearance. Some may have been pre-Cambrian, while others were much later. From an examination of inclusions it is known that certain gneisses were greatly folded and puckered before the Woodstock granite made its appearance. In like manner it may be inferred that in the case of the Sykesville area limestone had been laid down, gneiss had been crumpled, basic eruptives had broken through, and the whole had been tilted, before the granite appeared. This may have been as late, possibly, as the last great disturbance of the region preceding the Appalachian uplift. Certain it is that the acid eruptives were among the last of the igneous intrusions to disturb the rocks of the eastern Piedmont Plateau.

---

[1] Ann. de la géol. du Nord, t. XII, p. 106, 1885.

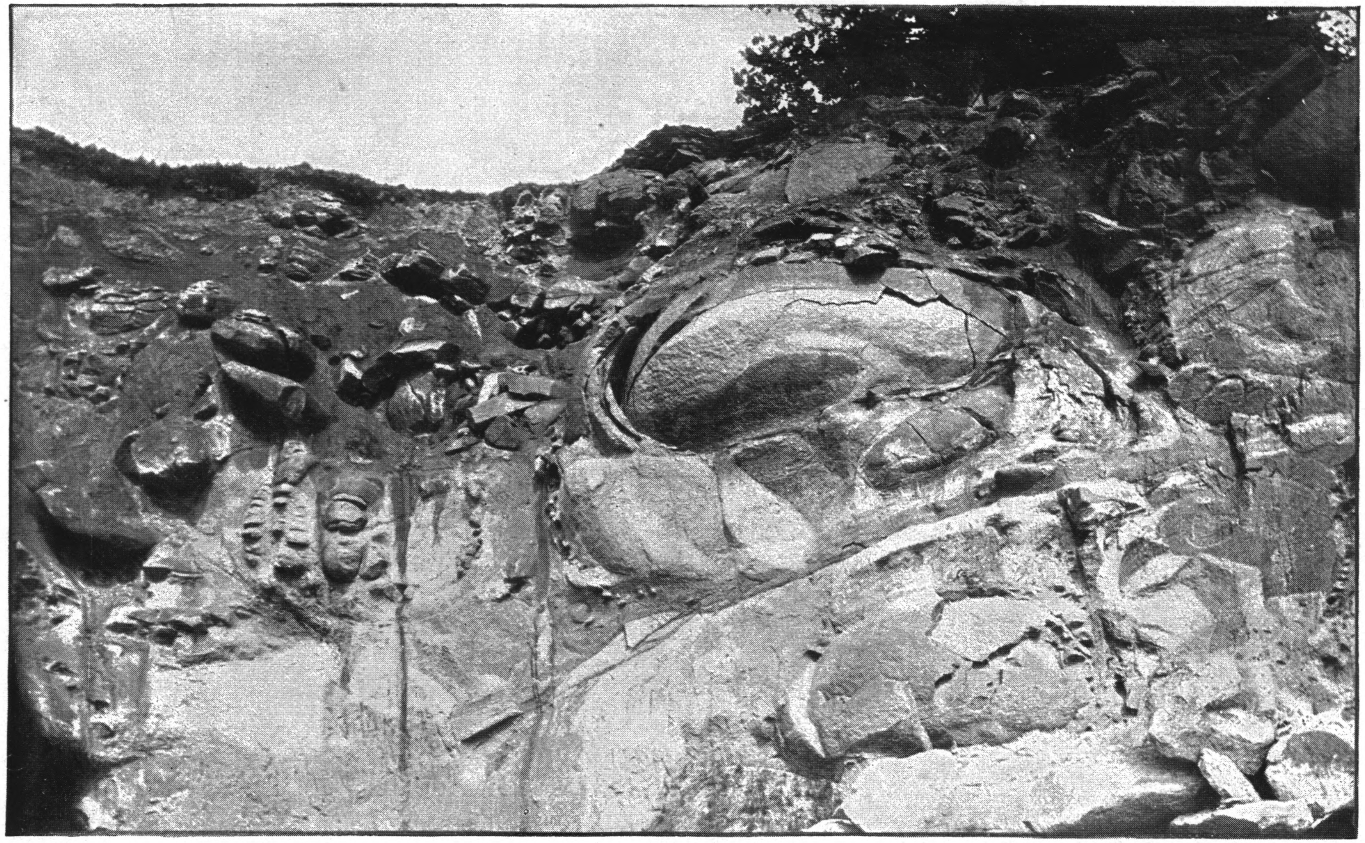
GENESIS OF CERTAIN MARYLAND GNEISSES.

More than one-half of the holocrystalline zone of the Piedmont region in Maryland is composed of gneisses, light-colored for the most part. Through these various eruptives have broken, so that there can be but little reasonable doubt that all of these have undergone more or less profound metamorphic changes.

From the observations set forth in the preceding pages there seems to be satisfactory evidence that among the granites certain ones are unquestionably of eruptive origin. The rocks of this character have always held an important place in the numerous and long-continued discussions relating to the general metamorphism of crystalline masses. Investigations have shown that the subject is far more complex than it was at first supposed to be, and that there enter into the problem a large number of important factors which it had been customary to ignore. Not the least active of these agencies is that of enormous orogenic pressure, superinducing a schistose structure in masses which have manifestly cooled from liquid magmas. Granites have been found elsewhere to be especially favorable to studies of this sort.

As shown by the microscope, the first effect of shearing in a normal granite is an optical disturbance in the quartzes and feldspars, especially in the former. This is the well-known phenomenon of undulatory extinction. These effects are seen in even the hard siliceous sandstones of mountainous regions. In Maryland the best example of this kind is the sandstone from Sugarloaf Mountain, a few miles east of Point of Rocks. As the tension increases the quartz is fractured and the grains become polysomatic; the feldspars develop a gridiron structure not unlike the cross-hatchings in microcline. Then, as the strain becomes still greater, the grains slip over one another, grinding off corners and edges and rounding the individual crystals. The "mortar structure" is thus produced. Or the shearing action may continue, the feldspars breaking down and becoming saussuritized. Schistosity, superinduced by mechanical movement, develops throughout the mass, and shearing planes form lines along which a new crystallization takes place, recementing the whole as firmly as before.

Briefly stated, then, this is the process which certain of the Maryland gneisses appear to have passed through in their formation from a mass that was previously granitic. This secondary acquirement of the schistose structure of true granite has been worked out in other places. It has been elaborately investigated in eruptive rocks by Törnebohm, Kjerulf, Lehmann, Rosenbusch, Teall, Schmidt, Reusch, and others in Europe; and in this country, around Baltimore and the Marquette region of Michigan, by Williams.



A GRANITE BOWLDER OF DISINTEGRATION, MIDDLE GRANITE QUARRY, NEAR WOODSTOCK, MARYLAND.

CHAPTER VI.

ECONOMIC BEARINGS.

The granite yearly quarried in the State of Maryland, according to the Eleventh Census report, recently published, amounts to about 3,371,000 cubic feet, valued at $447,489. Thus, among the States of the Union, Maryland ranks eleventh as a producer of granites. These rocks therefore assume considerable importance from an economic standpoint, in addition to the purely scientific interest they possess.

Although as a whole the granites have a very limited surface extent as compared with the other crystallines of the State, the different granitic areas are widely separated geographically. They furnish the most durable building stone of the region, and consequently, in all heavy masonry, massive architectural work, and in paving this rock figures largely.

The granite industry of Maryland is constantly increasing, the material being supplied not only for local use, but for shipment beyond the boundaries of the State. Yet the activity in this direction is not developed to the extent that it might be, for with the excellent railroad facilities Maryland granites should be more widely known than they are.

In the different granite districts the quarry industry is very unequally developed. This is probably due largely to accidental location as regards facilities for transportation, local markets, and means for removing the rock, rather than to any special inferiority of the respective deposits.[1]

Port Deposit.—The foliated biotitic granite which outcrops so extensively along the Susquehanna River in Cecil and Harford counties furnishes nearly one-half of the entire amount of granite quarried in the State. The rock of this region has been taken out in commercial quantities for more than three-quarters of a century. The output of the Port Deposit district during the year 1892 was nearly 80,000 tons, valued at about $220,000. Although somewhat gneissic in its character, the rock as a building stone is very durable. According to the tests made by the United States engineers, it withstands a crushing strain of over 18,000 pounds per square inch. Among the constructions built of this rock may be mentioned Fort Monroe and the artificial island opposite it on which Fort Wood was erected; Forts Carroll and McHenry, Baltimore; Fort Delaware; the sea wall at St.

[1] See Maryland; Its Resources. Industries, and Institutions, pp. 124–128 (Baltimore, 1893), for local history of the development of the stone industry in the State.

Augustine, Fla.; the navy-yard and dry dock at Portsmouth, Va.; the Naval Academy at Annapolis, Md; the foundation of the Treasury building, the Baltimore and Potomac Railroad station, and St. Dominic's church at Washington; the bridges over the Susquehanna at Havre de Grace, Md.; the Chestnut Street, Girard Avenue, Callowhill, and South Street bridges over the Schuylkill at Philadelphia; the principal bridges at Baltimore; and the new waterworks crib at Chicago. It has also been used in the construction of the entire plant of the Maryland Steel Company at Sparrow Point, Md.; at Haverford College; and in a large number of private and public dwellings in Baltimore and Philadelphia.

Gunpowder River.—The gray gneissoid granite of this area has not as yet been quarried extensively, though railroad facilities are excellent, the Baltimore and Ohio passing but a short distance from some of the best ledges. Openings have been made at several points, however, and a local demand for foundations and retaining walls supplied.

Texas.—The squeezed granite of this district has not been used much, and only a little of the rock has yet been quarried. It it not probable that this rock will ever be used to any great extent, as exhaustless quantities of good gneiss occur nearer the railroads and chief markets, and are, moreover, extensively quarried at and near Baltimore.

Relay.—Although small openings have been made within the limits of the district, little rock has been taken out. At the present time no quarrying of any kind is going on.

Guilford.—The light colored binary granite of Guilford, while evidently an excellent rock, is a couple of miles from railroad facilities, almost too far to compete successfully with localities more favorably situated. Three small quarries are in operation. Besides supplying local demands, the stone is hauled a mile and a half by wagons to the town, which is at the end of a long switch from the Metropolitan Branch of the Baltimore and Ohio Railroad, and there loaded on cars for transportation. The beautiful red granite reported from this place is found upon examination to be merely a surface staining of the typical white rock.

Ellicott City.—Recently considerable quarrying has been done in this area, the output for the year 1892 being valued at $22,500. The outcrops are almost continuous for several miles along the Patapsco River from Ellicott City to Ilchester. Near the former place the chief openings are the Werner and the Wilson quarries. A number of important buildings have been erected with the stone from this district. Among them may be mentioned the Cathedral at Baltimore, Ammensale College in Prince George County, and many substantial structures in Ellicott City.

Dorsey Run.—No quarries are in operation at this place, and the only rock taken out was used by the Baltimore and Ohio Railroad to protect the roadbed against the swift current of the Patapsco.

Woodstock.—Economically the granite of this district is one of the most important in the whole State. Its uniformity in grain and color

CONTORTED LIMESTONE INCLUSION IN GRANITE, SYKESVILLE, MARYLAND.

and the ease with which it can be obtained in blocks of almost any size make it one of the most desirable of the granitic stones for building purposes. Quarrying has been carried on for upward of sixty years. The first great impetus to the industry was given by the building of the Baltimore and Ohio Railroad down the Patapsco Valley, dressed stone stringers and material for bridges and culvert work being in demand. There are two principal quarries, the Waltersville and Fox Rock, besides several smaller openings. In the former extensive improvements have been made recently, steam being used for pumping, hoisting, drilling, and sawing the rock, and also for transporting it to the main line of the Baltimore and Ohio Railroad, 2 miles distant.

It is said that fully three-fourths of the stone used for fine granite work in the city of Baltimore has been procured at the Waltersville quarry. The same stone has also been used largely in Washington. Among the public buildings into whose construction it has in part at least entered may be mentioned the Capitol, Patent Office, Post-Office, and the new Library of Congress building. The stone from the Fox Rock quarry has also been used largely in Baltimore. Among the principal buildings constructed of it the Central Building of the Baltimore and Ohio Railroad and the Fidelity Trust and Deposit Building may be mentioned.

Sykesville.—Only one opening of any extent has been made in the granite at Sykesville. This is the Weller quarry, located about a third of a mile east of the Baltimore and Ohio Railroad station. At the present time no work is going on. A year ago Belgian paving blocks were taken out quite extensively. None of the stone was used for building purposes except for ordinary foundation walls.

Garrett Park.—Immediately north of the railroad station, on the south bluff of Rock Creek, considerable granite of a light color and of somewhat gneissoid structure has been quarried for local use. A couple of miles farther up the creek, near Halpin Station, a quarry has been opened in a very light-colored, almost white, granite, which is fine-grained and even-textured. The stone is of excellent quality and color and is used chiefly in Washington. The demand for the rock for fine building is rapidly increasing. North of Garrett Park 2 or 3 miles are more good exposures of an even-textured, rather fine-grained hornblende-granite. Small quantities of the rock have been taken out for local use, but no extensive quarrying has yet been done.

CHAPTER VII.

SUMMARY.

Recapitulating, several suggestive conclusions are to be deduced from the foregoing consideration of the granitic rocks in the eastern Piedmont zone of central Maryland.

I. CERTAIN OF THE GRANITES ARE ERUPTIVE IN NATURE.

This is shown by—

(1) *Field relations of the granitic masses.*—The granites penetrate and break through all the other rocks of the region—gabbros, diorites, pyroxenites, and gneisses. Those contacts which are observable are perfectly sharp, and in all respects are like the contact phenomena noticed in granitic dikes and other well-known eruptives.

(2) *Presence of inclusions.*—These are irregular fragments of rocks entirely foreign to the granites, but such as are found in the neighborhood of the granitic masses. They comprise limestone, sandstone, pyroxenite, micaceous and hornblendic schists, gneiss, and vein-quartz.

(3) *Characteristic contact phenomena.*—These are well defined, not only around the margins of the granite masses but also around the inclosed fragments of other rocks.

(4) *Microscopical examinations.*—Thin sections of the rock exhibit all the minute characters peculiar to well-known eruptives. Phenocrysts of both feldspar and quartz, as well as micropegmatitic intergrowths of quartz and feldspar, are not uncommon showing magmatic corrosion. In the vicinity of contacts the various zones are capable of being clearly made out and the metamorphic minerals are easily discerned.

(5) *Chemical analyses.*—Especially in the cases of contacts the relative acidities of the different zones correspond approximately with the theoretical and observed differences.

II. EPIDOTE IS AN ORIGINAL CONSTITUENT OF GRANITE.

The evidence of the primary occurrence of epidote in the eruptive rocks is essentially the same as that for allanite. Allanite, as is well known, is easily fusible, melting at a dull-red heat. This fact was long quoted as one of the most conclusive proofs against the eruptive origin of granites containing the mineral. It is now known that the mineral is widely distributed, and often an abundant accessory in such rocks as dacite, porphyrite, diorite, quartz-porphyry, and rhyolite, whose truly igneous nature can not be questioned. All physical obstacles as to its primary origin are thus manifestly removed. The evidence in any particular case that this mineral is either primary or secondary must therefore be derived largely from study of its association with other minerals.

Now, the epidote of certain of the Maryland granites is found in isomorphous growths with allanite as well as in separate well-defined crystals. Both minerals are found in sharply bounded individuals, and the following remarks apply to the intergrowths and the single crystals alike. From what has been said concerning both epidote and allanite in the foregoing pages, it may be inferred that—

(1) Allanite does occur as a primary constituent of undoubted eruptives.

(2) Epidote occurs similarly in perfectly fresh rocks or masses but slightly altered by orographic movement.

(3) The intergrowths under consideration of allanite and epidote are strictly isomorphous in character, and whatever is the genesis of the one is also the genesis of the other.

(4) Epidote in the intergrowths is not of pseudomorphic origin, as is well shown by the common occurrence of the parallel growths with sharply bounded outlines under conditions and surroundings identical with those of the pure, perfectly formed crystals of epidote alone.

(5) Long, isomorphous crystals of allanite and epidote are found bent and broken, the interstices and parted cracks being filled with biotite; the crystals often being continuous with, and optically oriented the same as, the surrounding black mica crystals, whose shape is partially given by the epidote. These fractures seem without doubt to be protoclastic in origin.

III. MUSCOVITE IS A PRIMARY MINERAL IN ERUPTIVE ROCKS.

For a long time muscovite has been regarded as an original constituent of certain of the most acid of the eruptive rocks. Recently, however, considerable doubt has been entertained by some writers as to whether this mineral really does occur as a primary constituent. The evidence that white mica is original in the very acid granites of Guilford, Md., is as follows:

(1) It occurs in large quantities in a perfectly fresh, very acid rock.

(2) It consequently is not derived secondarily from the feldspars nor from the bleaching or leaching out of the iron from the black mica.

(3) It forms parallel growths and intergrowths with biotite in sharply defined plates, with not the slightest sign of transition from one to another.

(4) It cuts and penetrates biotitic flakes at all angles, often giving shape to them.

IV. ORIGIN OF CERTAIN GNEISSES IS GRANITIC.

This is deduced from a series of observations pointing out clearly that—

(1) The region has been the field of great orogenic movements at various periods, during which powerful dynamic action has more or less intensely metamorphosed the rocks, both crystalline and sedimentary, over broad areas.

(2) The undoubted granites of the district show the effects of this great pressure in the development of the schistose structure to a greater or less extent.

(3) Varying degrees of schistosity are apparent in the same and also in different areas.

(4) Evidence of great shearing on the marginal zones of eruptive masses is well shown in the field, and under the microscope in the complete saussuritization of the feldspars.

(5) Mechanical deformation of the components of the rock is shown by the microscope in all stages in the different areas—undulatory extinction and polysomatism in the quartzes and feldspars, bending and twisting of mica plates and breaking of the included crystals of other minerals, cross-hatching in the feldspars, peripheral granulation and breakage of the component grains, and, finally, a partial recrystallization, with the various minerals arranged in a more or less distinctly banded manner.

INDEX

o