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OF

AMERICA

VOL. 8

JOSEPH STANLEY-BROWN, *Editor*

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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date eight volumes have been published.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America, not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending on the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, Rochester, New York.

Description of the published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	662 + xiv	23	63	4.50
Vol. 3, 1891	541 + xi	17	72	4.00
Vol. 4, 1892	458 + xi	10	55	3.50
Vol. 5, 1893	665 + xii	21	43	4.00
Vol. 6, 1894	528 + x	27	40	4.00
Vol. 7, 1895	558 + x	24	61	4.00
Vol. 8, 1896	446 + x	51	29	4.00

Brochures of Volume 8

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Eighth Summer Meeting, held at Buffalo, New York, August 22, 1896. H. L. Fairchild, *Secretary*	1– 16	....	....	$0.15	$0.30
Glacial flood deposits in Chenango valley. A. P. Brigham	17– 30	1	....	.15	.30
Correlation of Erie-Huron beaches with outlets and moraines in southeastern Michigan F. B. Taylor	31– 58	2	....	.25	.50
Diabase pitchstone and mud enclosures of the triassic trap of New England. B. K. Emerson	59– 86	3– 9	1–3	.60	1.20
Sheetflood erosion. W J McGee	87–112	10–13	....	.35	.70
Earth-crust movements and their causes. Joseph Le Conte	113–126	....	....	.15	.30

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Stratigraphy and paleontology of the Laramie and related formations. T. W. Stanton and F. H. Knowlton	127–156	...	1–2	$0.35	$0.70
Weathering of micaceous gneiss in Albemarle county, Virginia. G. P. Merrill	157–168	....	....	.15	.30
The Leucite hills of Wyoming. J. F. Kemp	169–182	14	1–3	.20	.40
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Age of the lower coals of Henry county, Missouri. David White	287–304	....	....	.25	.50
Nature, structure, and phylogeny of Daemonelix. E. H. Barbour	305–314	31–39	....	.50	1.00
Upper Cretaceous formations of New Jersey, Delaware, and Maryland. W. B. Clark, with the collaboration of R. M. Bagg and G. B. Shattuck	315–358	40–50	....	.65	1.30
Proceedings of the Ninth Annual Meeting, held at Washington, December 29, 30, and 31, 1896. H. L. Fairchild, *Secretary*	359–446; i–x	51	1–3	1.50	3.00

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued either wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 8 have been issued:

Editions uniform with the Brochures of the Bulletin

Pages 17– 30, plate 1;	230 copies.	January	11, 1897.
" 31– 58, plate 2;	130 "	"	21, "
" 59– 86, plates 3–9;	130 "	February	13, "

Pages 87–112, plates 10–13;	30 copies.	February	13,	1897.
" 113–126,	30 "	"	15,	"
" 127–156,	80 "	"	17,	"
" 157–168,	80 "	"	22,	"
" 169–182, plate 14;	230 * "	"	25,	"
" 183–196, plate 15;	30 "	"	27,	"
" 197–212, plate 16;	230 "	March	5,	"
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" 227–240, plates 21–22;	130 "	"	8,	"
" 241–250, plates 23–24;	230 "	"	12,	"
" 251–268, plates 25–29;	130 "	"	23,	"
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" 305–314, plates 31–39;	280 "	April	14,	"
" 315–358, plates 40–50;	280 "	"	15,	"

Special editions †

Pages 3– 5, ‡	30 copies.		December	31,	1896.
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CORRECTIONS AND INSERTIONS

All contributors to volume 8 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention :

Page 5, line 7 from bottom; *for* "Pleistoiene" *read* Pleistocene
" 11, " 2 " top; *for* "Newbury" *read* Newberry
" 35, " 2 " bottom; *for* "Superior" *read* Erie

* 200 of these were without covers.
† Bearing the imprint ["From Bull. Geol. Soc. Am., vol. 8, 1896"].
‡ Fractional pages are sometimes included.

Page 38, line 18 from bottom; *strike out* "the land features in the interval are so simple" and *insert* the Belmore (Ridgeway) was followed continuously by Spencer, and the slope was also examined by him on three transverse lines, so

" 60, " 3 from top; *for* "New England" *read* Massachusetts

" 67, " 19 " " ; *for* "Whipple" *read* Whittle

" 67, " 16 " bottom; *for* "Whipple" *read* Whittle

" 70, " 18 " " ; *for* "albite-calcite-diopside" *read* albite, calcite, diopside

" 70, " 5 " " ; *after* "The" *insert* rare

" 78, " 17 " " ; *for* ".03" and ".07" *read* 3 and 7

" 78, " 16 " " ; *for* "$.01\frac{1}{2}$" *read* $1\frac{1}{2}$

" 85, " 10 " " ; *for* "Directly below" *read* Directly to the left

" 98, " 8 " " ; *for* "ibbon" *read* ribbon

" 107, " 2 " top; *for* "baseleveled" *read* planed

" 107, " 25 " " ; *for* "baselevel" *read* graded

" 108, " 4 " bottom; *for* "baselevel" *read* graded

" 109, " 14 " top; *for* "examples" *read* example

" 110, " 6 " " ; *for* "baselevel" *read* plain

" 110, " 24 " " ; *for* "baselevel" *read* graded

" 111, " 16 " " ; *for* "baselevel" *read* graded

" 112, " 6 " bottom; *for* "baseleveled" *read* planed

" 113, " 10 " " ; *omit* "those of"

" 113, " 10 " " *for* "it" *read* the same

" 113, " 7 " " *for* "this" *read* the

" 120, " 11 " " *omit* "—" after "downward"

" 121, " 7 " top; *for* "the area" *read* this area

" 122, " 14 " bottom; after "Herschell" should be reference to following foot-note: Geol. Soc. London, vol. ii, 1857, p. 548

" 123, " 18 " top; *for* "it is more" *read* it is still more

" 125, " 4 " " ; *for* "in" *read* on

" 136, " 20 " bottom; *for* "*Castalea*" *read* *Castalia*

" 142, " 4 " top; *for* "Foobes" *read* Forbes

" 145, " 11 " bottom; *for* "*Conus*" *read* *Cornus*

" 167, " 1 at top; *for* "176" *read* 167

" 169, *insert* the following note on the occurrence of leucite:

Two additional localities for leucite have been casually mentioned. J. Curie et G. Flausand, in a pamphlet entitled "Étude succincte sur les Roches eruptives de l'Algerie," which is reviewed in the Neues Jahrbuch, 1890, volume ii, page 406, mention leucite-basalt at Ain Temouchement, Algiers. F. W. Hutton, in a paper on the igneous rocks of New Zealand, published in the Proceedings of the Royal Society of New South Wales, volume xxiii, 1889, page 105, states, in a foot-note, that W. Skey had mentioned a leucite-basalt from near Castle Point, on the east coast of Wellington. Skey's announcement is referred to as original in the Col. (Colonial?) Museum and Laboratory Reports Number 10, page 48, a publication not accessible to the writer.—J. F. K.

Page 171, line 9 from top: leucite-absarokite has *not* been found in place

" 181, VII; analysis made for Arnold Hague, *not* J. P. Iddings. See Am. Jour. Sci., vol. xxxviii, 1889, p. 47

" 198, lines 20–21 from top; *omit* and the outcrop on the cliff of the more important thrust-planes

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
Vol. 8, pp. 1-16 December 31, 1896

PROCEEDINGS OF THE EIGHTH SUMMER MEETING, HELD AT BUFFALO, NEW YORK, AUGUST 22, 1896

Herman Le Roy Fairchild, *Secretary*

CONTENTS

Session of Saturday, August 22

The Society was called to order at 8 o'clock p m in the lecture-hall of the Buffalo Society of Natural Sciences, in the Library building, the President, Professor Joseph Le Conte, in the chair.

After introductory remarks the President stated that, in accordance with the decision of the Council and the announcement of the Secretary, the meeting was to be limited to a single session for transaction of administrative business and the reading of papers by title. The papers so read by title would be presented and discussed before the Section of Geology of the American Association for the Advancement of Science during the subsequent week.

ELECTION OF FELLOWS

The Secretary announced the result of the balloting for Fellows, as canvassed by the Council, as follows:

Fellows Elected.

Jose Guadalupe Aguilera, Escuela N. de Ingenieros, Mexico, D. F. Director of the Instituto Geologico de Mexico.

Philip Argall, Denver, Colorado. Mining engineer.

Ezequiel Ordonez, Escuela N. de Ingenieros, Mexico, D. F. Geologist of the Instituto Geologico de Mexico.

Thomas Wayland Vaughn, B. S., A. B., A. M., Washington, District of Columbia. Assistant Geologist, U. S. Geological Survey.

Henry Stephens Washington, B. A., M. A., Ph. D., Locust, Monmouth county, New Jesey. Mineralogist and geologist.

George Hall Ashley, M. E., A. M., Ph. D., San Bernardino, California. Teacher. Now engaged in studying the stratigraphy and paleontology of the Tertiary.

REPORT OF COMMITTEE ON MOUNT RAINIER FOREST RESERVE

The following report of the special committee of the Mount Rainier Forest Reserve was read by the Secretary:

To the Council of the Geological Society of America:

The Committee on the Mount Rainier Forest Reserve have to report that they have conferred with the President of the General Committee and with Senator Squire, who has charge of the bill for creating a national park in that region, to be called the Washington National Park, at several times during the winter. They have urged that an appropriation be made for surveying the area selected, and making a topographic map of the same, under the auspices of the U. S. Geological Survey, thinking that this would facilitate the passage of the bill by making the region better known to the public.

Unfortunately it has proved impossible to obtain any action by Congress during the past session, but it is hoped that during the coming winter greater success may attend their efforts.

Respectfully submitted.

S. F. Emmons,
Bailey Willis,
Committee.

Washington, *June* 17, 1896.

The report was accepted and the committee continued.

President Le Conte made some remarks on the importance to the western country of forest reserves and national parks.

Upon motion of J. J. Stevenson, it was voted that President Le Conte be requested and authorized to represent the Society at the session of the American Association for the Advancement of Science to be held in honor of the completion by Dr James Hall of sixty years of official work upon the geology of New York.

SECRETARY'S REPORT ON GEOLOGICAL EXCURSIONS

The Secretary made the following report on the geological excursions which had been planned as partial substitution of the usual Summer Meeting of the Society:

Four excursions had been offered, to cover the days from Monday, August 17, to Saturday, August 22, inclusive, and open not only to the Fellows of the Society, but to members of the American Association for the Advancement of Science and to all other persons who desire to take advantage of them, without charge excepting the expenses of subsistence and transportation. A circular giving an itinerary and mention of the various points or objects of interest which it was proposed to visit, with lists of geological writings bearing upon those features, had been widely distributed.

The excursion in stratigraphy and paleontology planned to include central and western New York, under the conductorship of Professor Charles S. Prosser, and that in the economic geology of western New York, under Dr F. J. H. Merrill, had been abandoned at the last on account of lack of sufficient interest.

The excursions in petrographic geology, under the guidance of Professors J. F. Kemp and Charles H. Smyth, Jr., and in Pleistocene geology, under the guidance of the Secretary and Mr G. K. Gilbert, were carried out successfully. It had been expected that Mr Frank Leverett would assist in the latter excursion, but he was prevented by illness.

Professors W. N. Rice and C. H. Hitchcock were called upon to give an account of the work of the petrographic excursion. They spoke as follows:

REMARKS ON THE PETROGRAPHIC EXCURSION

BY W. N. RICE AND C. H. HITCHCOCK

Professor W. N. Rice spoke as follows:

The party assembled at Port Henry, on lake Champlain, on Monday, October 17, and the first three days of the week were devoted to the study of the eastern part of the Adirondack region, under the guidance of Professor J. F. Kemp.

Monday forenoon was spent in the study of the crystalline limestones, gabbros and gneisses north of the town and near the lake shore. Special attention was called to the gneissoid modifications of the gabbro, the transition being shown from a typical massive gabbro to a rock which is essentially a hornblende gneiss. The contacts between the gabbro and the limestone formed another feature of special interest. Tongues of gabbro were seen projecting into the limestone, sometimes apparently isolated from the main body of the gabbro. The phenomena would seem to indicate intense dynamic action subsequent to the consolidation of the gabbro. While some of the bands of dark silicates enclosed in the limestones appear to be pretty certainly extensions of the gabbro, others may be thin strata of schist resulting from the metamorphism of silicious sediments which were originally interstratified with the limestones.

Monday afternoon the party visited the great magnetite mines at Mineville, and the complex stratigraphic relations of the ore bodies were explained by Professor Kemp. The ore occurs on the contact between underlying sheets of gabbro, often metamorphosed to hornblende gneiss, and an overlying quartzose gneiss. Associated with the magnetite at Mineville, are veins of an oligoclase pegmatite containing beautiful crystals of zircon, of which numerous specimens were obtained.

Tuesday the party embarked in a steam-launch, intending to cruise along the lake shore to Plattsburg, and study as many of the dikes and other interesting geological features near the lake as possible, The titaniferous magnetite at Splitrock mine was examined. This, like all the deposits of titaniferous magnetite in the Adirondack region, was held to be simply an extremely basic segregation from the magma of the gabbro. Not as many of the localities of dikes and other interesting geological phenomena were visited as had been intended, on account of heavy squalls of wind, accompanied by violent rain and hail, which delayed the launch and made a landing at some of the points impossible. It was therefore left at Burlington, and we proceeded to Plattsburg by the large steamer which makes regular trips on the lake.

On Wednesday the party took an early train to Ausable Forks, and went from there by stage through the Wilmington notch to lake Placid. The views of the imposing peak of Whiteface and the tremendous precipices which bound the Wilmington notch on both sides are among the finest scenery in the Adirondacks. The deep and narrow gorge of Wilmington notch, with its remarkably abrupt walls, was explained as probably the result of great faults. Outcrops of anorthosite of several varieties were observed along the road; and the noonday halt for lunch was made beside a most picturesque cascade, where the West branch of the Ausable river plunges over ledges of granite, intersected by a most interesting network of trap dikes. From lake Placid the party proceeded by rail to Norwood, and thence by an early train Thursday morning to Gouverneur.

Thursday and Friday were spent in the region of Gouverneur under the direction of Professor C. H. Smyth, Jr. Thursday was occupied in the study of the gneisses and limestones in the immediate vicinity of the town. Two types of gneisses were recognized, quite distinct from each other in character, and very probably in origin. One type of gneiss is prevailingly red in color, never very distinctly foliated, though sometimes acquiring a conspicuously banded appearance by the presence of inclusions resembling a biotite or hornblende schist. In some cases this gneiss appears to pass into a truly massive granite. The phenomena seem to indicate that this gneiss is truly a granite, altered by dynamic metamorphism. The other type of gneiss is predominantly dark gray, and very conspicuously bedded. It has more the appearance of being a metamorphosed sedimentary rock.

Friday forenoon the party visited the talc mines at Talcville. The alteration of enstatite and tremolite into talc was shown by various transitional stages. Specimens were obtained of a beautiful purple variety of tremolite for which the locality is noted.

Friday afternoon the party visited the famous locality of crystalline danburite in the town of Russell. The danburite, and the huge crystals of pyroxene and biotite which are found in the same vicinity, may be derived from a stratum of limestone which has undergone so extensive alteration that the greater part of the calcite has disappeared. From the danburite locality the party proceeded to a remarkable exposure of gabbro, also within the limits of the town of Russell. At this locality part of the gabbro shows essentially the typical character of the rock. Other portions are decidedly gneissoid. In some parts, the rock shows, in addition to a schistose structure, a peculiar concentric banding.

Friday evening the party returned to Gouverneur; and Saturday morning the members scattered to their various destinations. The whole number that participated in this excursion was fourteen, though not all of them were present any one day.

Professor Charles H. Hitchcock spoke as follows:

I will speak only of the part of the Pleistocene excursion supervised by Professor J. F. Kemp, in the eastern part of the Adirondacks during the first three days of the week. At Port Henry, near lake Champlain, we saw breccias produced by the shattering of the older gneisses, adjacent to a thoroughly crystalline limestone precisely like what has been known as Laurentian; all these rocks underlying the Potsdam. In a quarry farther west we were able to see this same limestone traversed by a basic dike, where there were evidences of the flow of the limestone around and between the fragments of the igneous intrusion. This is evidently of that class of phenomena that led Emmons to say that the "primary limestone" had been melted. He saw evidence of flowage and assumed it to have been the result of igneous agency. At Mineville we saw one of the largest of the magnetic iron ore beds, or rather two of them, roughly parallel to each other, with the associated gneisses and pegmatites. We amused ourselves by breaking out zircons from the debris, and were kindly entertained by Dr and Mrs Saville.

Most of Tuesday was spent in sailing down the lake in a steam-yacht, stopping particularly at Split rock, where we examined a body of titaniferous ore in gabbro. The presence of the titanium renders the separation of the iron too costly to be profitable. Small portions of the vein seemed to have been fused into a glass. We also explored a dike of camptonite at Essex, in the Chazy limestone.

On Wednesday we moved from Plattsburg to the Ausable forks by rail, noting immense masses of sand brought down to the ancient Champlain ocean and deposited as a glacial delta. At Jay and Wilmington the rocks are largely gabbros and norites, which exhibit signs of universal fracture or crushing. The larger pieces consist of lime feldspars so placed that they have evidently been broken apart, while the finer-grained matrix consists of the same mineral pulverized. These veins have only been developed recently by the modern students of petrography. Remarkably smooth and polished, glaciated anorthosites were visited at lower Jay.

In order to utilize my opportunities, I left the party in Wilmington for the purpose of studying the glaciation of the higher mountains. The results of my observations are not appropriate in this connection.

Judging from my own experience I think the custom of engaging in a few days of field-work before our summer meetings is a decided benefit. All our Fellows would find it to their advantage to improve these opportunities as they may be offered from year to year.

For an account of the Pleistocene excursion Professor W. H. Niles was called upon, and gave the following report:

REMARKS ON THE PLEISTOIENE EXCURSION

BY W. H. NILES

The excursion for the study of Pleistocene geology in central-western New York was successfully made, notwithstanding the fact that Mr Frank Leverett was prevented by illness from conducting the party over the region west of Batavia. Professor H. L. Fairchild, of Rochester, conducted the party not only for the three days as first planned, but very kindly continued to serve for two additional days.

There were twelve persons who availed themselves of the opportunity during some portion of the time. The presence of Mr G. K. Gilbert during the first three days was appreciated by the others in attendance. The itinerary as given in the circular was pretty closely followed for these days. The examination of the Iroquois shore-line, along what is known as the "ridge road" in the northern part of Rochester, and of a part of the old delta of the Genesee, furnished a good introduction to the studies of the week.

The visit to the "Pinnacle hills" in the southern edge of Rochester gave the party a clearer idea than had been anticipated of the origin and the geological relations of these features which have been regarded as problematical. The evidences that one portion of the range is a genuine moraine were perfectly conclusive. Satisfactory indications were observed that the finer materials of other portions had been selected and deposited by waters which were associated with the ice in its work. There were clear topographic indications that static waters had occupied a basin extending southward from this range of the Pinnacle hills. These features, together with the curvature in the trend of the hills, the difference in the steepness of the slopes, the occurrence at all altitudes of boulders of Niagara limestone, some of which were distinctly glaciated, and the arrangement of the finer materials with reference to the coarser, combine to sustain Professor Fairchild's conclusion that here was the southern edge of a lobe of glacial ice which brought and deposited the fundamental part of the range as a moraine, while the waters flowing from the melting ice and the waters accumulated on the south distributed the finer material in such a manner as to give the complex character for which the hills are noted. The latter portion of the first day was spent in a trip around the head of Irondequoit gorge observing the extensive terraces and kame deposits.

The next morning the party took the train from Rochester to Victor. A walk of six miles to Millers Corners was through an interesting and very diversified kame area. In this district there is a large number of irregularly arranged hills of very steep slopes, some of them with flattened summits, which rise to a tolerably uniform level approaching 900 feet. They indicate a height of standing water, but the party discussed whether the upper plain was to be regarded as one of erosion or one of deposition. Through the kindness and generosity of Mr E. P. Clapp the party was provided with transportation by carriages from West Rush to Avon, spending the middle portion of the day in the region around East Avon. Three localities were there visited where the ancient beaches and shore deposits were exceedingly well preserved. The widespread occurrence of static waters at this level, about 880 feet, was conclusively demonstrated by the well defined shore features which are still retained. The party did not have an opportunity of following these to their full extent, but Professor Fairchild believes they may be traced to a connection with the Crittenden beach, and thus establish a complete chain of evidence of the eastward extension of the Warren waters.

Wednesday morning, August 19, a visit was made to the postglacial gorge of the Genesee at Mount Morris, and then the cars were taken for Canaseraga. Between Nunda and Canaserada two lines of railway traverse an outlet of a glacial lake which once occupied the Nunda valley. The members of the party were much impressed with the distinctness of this outlet as evinced by the steep walls of rock forming the lateral boundaries of the gorge-like transverse valley, and they were also interested in the well characterized drift deposits occurring at the head of the gorge, and revealing its preglacial origin. From Canaseraga the party walked to the head of "Poags hole," and thence to Burns, observing en route features of glacial, lake and stream origin which are regarded as having been formed at the time of the fifth and sixth stages of Genesee glacial waters, when they found an outlet through this locality to the Susquehanna. The party spent the night at Portage.

After a view of the gorge of the Genesee at Portage and an opportunity for seeing how a preglacial gorge had been filled with drift, diverting the course of the stream, the party went by rail to Alden. Here they followed a southern branch of the Crittenden beach eastward to the county line, thence went northward to the Crittenden beach proper, which was followed to Crittenden station. The party remarked that the beaches which they had seen at East Avon equalled in distinctness those which they found here.

Thursday evening the party deviated from the plan, as laid down in the circular for Friday and Saturday, on account of the absence of Mr Leverett and the reduced number. The party took train via Buffalo to Hamburg, where the heavy Warren beaches were inspected. The members then became the guests of Mr B. W. Law, at North Collins, who entertained them not only for the night, but likewise for the next day by driving about the region, giving excellent opportunities for the examination of the high terraces along the Cattaraugus creek, and for inspecting one of the most interesting postglacial gorges of the district.

Announcements were made concerning the excursions, work, and entertainment of the following week.

The President announced the scientific program in order, and the Secretary read the following papers by title, in accordance with the plan of the meeting:

SHEETFLOOD EROSION

BY W J MCGEE

The paper is printed in full in this volume.

CUYAHOGA PREGLACIAL GORGE IN CLEVELAND, OHIO

BY WARREN UPHAM

Contents

INTRODUCTION.

Since the publication of my paper on the "Preglacial and postglacial Valleys of the Cuyahoga and Rocky Rivers," * read at the last meeting of this Society, information has been supplied by Mr S. J. Pierce, of Cleveland, derived chiefly from

* Bull. Geol. Soc. Am., vol. vii, pp. 327–348, with map and sections.

deep well borings which have been made during several years past under the direction of Mr F. S. Gilbert, contractor, also of Cleveland, showing that the preglacial Cuyahoga valley in its last eight miles, passing through Newburg and Cleveland, has a depth of 350 to 470 feet below the surface of lake Erie. At the time of my writing and publication of the paper mentioned, the deepest well section in the drift at Cleveland which had come to my knowledge was that recorded by Newberry near the mouth of Kingsbury run, reaching the bed rock of shale 228 feet below the level of the river and lake. Even that depth of drift revealed a very interesting preglacial valley and different conditions of topography and drainage from those of the present day; for the greater part of lake Erie, as is well known, is only about 80 feet deep, while its maximum depth, apparently in an old river valley now covered by the lake, is only 210 feet. It was also ascertained by Newberry, from borings for oil, that where the Cuyahoga river enters Cuyahoga county, about thirteen miles from the lake Erie shore at Cleveland, the bottom of the preglacial gorge is 220 feet below the present river, or about 175 feet below the level of the lake.

Records of Wells in the glacial Drift.

The most southerly well, that is, the one farthest up the Cuyahoga valley, of which Mr Pierce supplies me records, was bored by Mr D. B. Duff on the bottomland of the Cuyahoga river in the north edge of Independence township, about eight miles distant in a direct line from Gordon park, where the deeply eroded preglacial gorge passes under the present lake shore. It was bored at the works of the Newburg Fertilizer Company, about a quarter of a mile south of the southern line of Newburg township, and passed through many alternating deposits of gravelly and stony clay (till) and stratified gravel, sand and clay to a total depth of about 350 feet, where it was abandoned without reaching the bed rock (shale). This well is about 17 feet above the mean level of lake Erie; hence it finds the preglacial gorge there to exceed a depth of 333 feet below the lake surface, or 123 feet below the deepest place in the lake bed.

The relative levels will be made more clear by the following notes of altitudes determined by leveling, for which I am indebted to Mr C. G. Force, chief assistant city engineer of Cleveland. They are given in feet and are referred to mean tide sealevel, according to my Bulletin 72, United States Geological Survey, pages 15, 147:

Zero reference of Cleveland city levels (high water of lake Erie in 1838), 575.20.

Lake Erie (maximum depth, 210 feet), lowest stage at Cleveland (in 1819), approximately, 570; highest stage (in 1838), 575; mean annual low and high stages, 571–574; mean surface, January 1, 1860, to December 31, 1875, 572.86.

Ohio canal below the Eight Mile lock, near this well in Independence, 587.

Cuyahoga river at the head of its portion level with lake Erie during the river's stage of least flow, about a half mile below the Eight Mile lock, according to observations by Mr Force during ten consecutive days in the summer of 1895, 570.5–571.

At that time the level of lake Erie was unusually low, being four to five feet below the Cleveland base or zero of levels. Owing to the effect of winds on lake Erie, raising its surface at the mouth of the Cuyahoga, the level of the river there was occasionally, during Mr Force's ten days of observations, higher (to a maximum of two and a half inches) than it was at the rear of the Infirmary farm, about seven and a half miles above its mouth and near the Independence well.

Another well was bored by Mr Duff in C. G. Barkwill's brickyard, near the corner of Mound and Seabrook streets, in Cleveland, two and three-fourths miles north of the foregoing, at the height of 108 feet above the mean level of the lake. It was abandoned at the depth of 323 feet without penetrating to the shale.

Half a mile west-southwest from the last a well near the entrance of Forest City park, 112 feet above the mean lake level, went to a depth of 300 feet and stopped without reaching to the bed rock. This and all the following wells are reported by Mr Pierce from notes by Mr F. S. Gilbert, under whose direction they were bored.

Along or near the course (approximately east to west) of Euclid avenue and Detroit street through the city of Cleveland, the former east and the latter west of the Cuyahoga river, on and near the lower and principal Crittenden beach,* at the height of 95 to 100 feet above the lake, twenty wells are reported, as arranged in the following table, their order being from east to west, with their distances from the Garfield monument and their respective depths to the bed rock (shale). The Garfield monument, in the Lakeview cemetery, stands at the eastern city boundary, on the margin of the eastern bluff of the broad Cuyahoga valley, overlooking the city and lake, the altitude of the ground at the base of the monument being 250 feet above the lake level. Only a thin deposit of the glacial drift, mostly from 2 or 3 to 10 or 15 feet deep, lies on the crest of this bluff or escarpment along its extent of five miles southwesterly, coinciding nearly with the eastern limits of the city, from the Garfield monument to Newburg. Farther back (eastward) from the Cuyahoga valley this upland gradually rises, and has mainly a somewhat greater thickness of drift, though quite incomparable with the great mass of drift which was laid down in the river valley.

Wells along or near Euclid avenue and Detroit street.

	Distances in miles from the Garfield monument.	*Depths of drift in feet.*
Adelbert street	0.9	12
Fairmont street	1 1	12
Republic street	1.3	15
Amesbury avenue	1.5	35
Lincoln avenue	1.9	125
East Madison avenue	2.1	346
Giddings avenue	2.4	440
Willson avenue	3.0	325
Case avenue	3.3	320
Dodge street	4.4	250
Erie street (Hollenden hotel)	4.7	220
Public square	5 0	205
On the Cuyahoga bottomland †	5.5	110
Division street near the water works †	6.3	108
Waverly avenue	6.9	104
Lake avenue and Detroit street	7 5	75
Lake avenue and Edgewater park	7.9	55
Near Mueller avenue	8.4	40
Near Parkview avenue	9.2	35
Near Highland avenue, at the western city boundary	9.5	20

On this section, nine and a half miles long, crossing the city of Cleveland, the

* See the map of Cleveland accompanying my paper before cited (Bull Geol. Soc. Am., vol. vii).
† These two wells are on ground nearly 100 feet lower than the other wells of this list.

greatest depth of the preglacial valley is found at Giddings avenue, about two miles from the eastern bluff. The depth to the bed rock there is 440 feet, reaching 340 feet below the level of lake Erie. From the top of the bluff at the Garfield monument to the bottom of the ancient gorge is a vertical depth of 590 feet. Within a half mile east from Giddings avenue, the side of the gorge, under the drift, has an ascent of 315 feet. The western side has a more gentle slope, rising 115 feet in about a half mile, and thence rising about 120 feet in the next two miles to the Public square. Thence the old valley bed is nearly level for more than a mile, to the vicinity of the water works; but farther west it rises about 100 feet in little more than a half mile and continues to rise more slowly to the western city limits.

It is probable, however, that this section, as revealed by the wells recorded, fails to reach the deepest point of the old valley. Another well on Giddings avenue, near Lawnview and Astor avenues, about half a mile north of Euclid avenue and on land about 15 feet lower, has the depth of 475 feet to the bed rock, which is reached thus about 50 feet lower than near the intersection of Euclid and Giddings avenues.

South of the Euclid avenue section, a well near the intersection of Woodland avenue and Jackson street, a mile southwest of the Case avenue well in the foregoing list, reached the bed rock at 320 feet. It is on ground about 105 feet above the mean lake level.

There remains to be noted only one other well, but this shows the greatest depth of drift yet found, and it is the most northern and nearest to the lake shore, being situated near the junction of Bratenahl street and Girard avenue, on the east line of Gordon park. This well was bored, according to Mr Duff (in company with Mr Gilbert), to a depth of 520 feet, and was then abandoned without reaching the base of the drift. The ground there is about 50 feet above the lake, which is a third of a mile distant on the north. The bottom of the preglacial valley near its place of passing out beneath the lake is thus at least 470 feet below the lake level.

Inspecting these records, we find that, within the area of the city of Cleveland, the line of maximum depth of the old valley lies near its eastern side and runs north-northeastward, passing near the Forest City park, the intersection of Giddings and Euclid avenues, and Gordon park. Where the preglacial Cuyahoga gorge enters this county it had already attained a depth of 175 feet below the present lake; in the northern edge of Independence township its depth below the same plane is 333 feet, without there reaching the bed rock; at Giddings and Euclid avenues its depth is at least 340 feet; a half mile farther north it is 390 feet, if not more; and at Gordon park it is known to exceed 470 feet.

Because of the greater expense of boring in the drift than in the underlying shales, the base of the drift has been carefully determined; but the succession of diverse drift deposits, and their respective thicknesses, have not been so noted. Concerning the characters of the drift, Mr Gilbert informs me that, beneath the superficial Cuyahoga delta sand and gravel, usually 10 to 20 feet deep, as described in my former paper, a considerable thickness of stony and gravelly clay or till is passed through, with occasional enclosed beds of stratified gravel and sand; but that the lower portion of some of the very deep drift sections consists chiefly of sand and gravel, resembling those of the present lake beaches. In the till of the well at the Public square he bored through a log fully two feet in diameter, thought to be oak, at the depth of 125 feet. In this well a stratum of seven feet of very fine quicksand lay immediately upon the shale; but in some other deep wells the lowest drift deposit is clay, probably till.

In the well of the Standard Oil Company, near where Kingsbury run joins the Cuyahoga river, the section of the drift reported by Newbury,* including the drift bluff above the well, measures 323 feet. Subtracting the 25 feet of delta sand at the top, the remaining 298 feet consists mainly of till, but incloses four distinct seams of stratified sand, ranging from 10 to 18 inches thick, and, below these, three seams of gravel and sand, ranging from 2½ to 5 feet thick. Two of these last-named deposits, occurring within the last 20 feet before coming to the shale, are coarse gravel, in each case about 3 feet thick, but the lowest 8 feet are clay (till). In the entire 298 feet from the top to the base of the till, it incloses at that locality an aggregate of only 17 feet of the intercalated seams of modified drift.

Probable drainage Conditions of the Lake Erie Basin before the Ice Age.

The area now occupied by the great Laurentian lakes tributary to the Saint Lawrence river seems to me to have probably discharged its drainage during the Tertiary era and until the Glacial period in the opposite direction, flowing west and south to a trunk stream which ran along the bed of lake Michigan and onward to the gulf of Mexico. This view I have more fully stated in another paper presented at this meeting,† and therefore need not dwell especially upon it here. Through the very long Tertiary era a great river system, if my view be true, flowed with continuous and unobstructed slopes westward and southward, where later, by the epeirogenic movements preceding and accompanying the accumulation and departure of the ice-sheet, the earth's crust became deformed so that portions of the former river valleys are now depressed to maximum depths (in the beds of lakes Ontario and Superior) of nearly 500 feet beneath the sea level.

The preglacial drainage channels, now largely drift-filled, which connected the Laurentian lakes have been well studied by Mr J. W. Spencer, who concludes that such a channel joins lake Ontario with Georgian bay, passing along the northern side of the great Niagara escarpment; but I differ from him in my belief that the Tertiary and preglacial river of these basins and channel flowed westward, whereas he supposes it to have run easterly to the gulf of Saint Lawrence, in accordance with which view he has named it the Laurentian river.‡

Very probably the Erie basin outflowed northwestward, with descent away from the more elevated Appalachian mountain belt, either to the west part of the valley which is now lake Ontario, or in part or wholly past lake Saint Clair directly into the lake Huron valley. The westerly converging streams of these three lower Laurentian lakes, according to my view, united with a great river from the lake Superior basin, so forming the Michigan river, which thence passed south to the sea.

Epeirogenic Movements during the Quaternary Era.

The deep preglacial valleys of the Cuyahoga and Rocky rivers, tributary to the basin which now holds lake Erie, testify, with many other similarly deep and drift-filled preglacial river courses, throughout the interior of our country, that immediately before the Ice age this continent was uplifted much above its present

* Geology of Ohio, vol. ii, 1874, p. 24.

† "Origin and Age of the Laurentian Lakes and of Niagara Falls," published in the American Geologist, Sept., 1896.

‡ Proceedings of the Am. Assoc. for Adv. of Science, vol. xliii, for 1894, pp. 237-243; and numerous earlier papers.

altitude, giving steeper gradients and increased power of erosion to the streams. The duration of the uplift, however, was not geologically long; else the narrow gorge of the Cuyahoga would have become a wide valley, and, on the borders of the continental plateau, the fiord-like submarine continuation of the Hudson and other rivers, and the northern and Arctic fiords, would have been widened to mature valleys, with extensive lowland plains and gently sloping sides.

During the Glacial period (which I think to have been brought on by the cold and snowy climate at the culmination of the uplift), the land, under the burden of its ice-sheet, was isostatically depressed, so that when the consequent return of a warm climate on the borders of the ice melted it away the country was somewhat lower than now. By this northern differential depression the region of the Laurentian lakes became tributary to the Saint Lawrence, which before the Ice age, as I think, had received its farthest supplies from the Champlain and Ottawa valleys.

In the ensuing moderate re-elevation from the Late Glacial or Champlain subsidence, the basins of the four great lakes above lake Ontario lacked only a little more northeastward uplifting to turn their drainage again to the Mississippi and gulf of Mexico by discharge from lake Michigan at Chicago along the course of the outlet of the ice-dammed lake Warren. If the east end of the lake Erie basin were raised only about 40 feet higher (a small fraction of its actual uplift from the Champlain depression), or, conversely, if the southern part of the Michigan basin should sink 40 or 50 feet, the Niagara river would cease, and the waters of these four upper lakes would pour along the Des Plaines and Illinois valleys.

Deposition of glacial and modified Drift in Cuyahoga Valley and Lake Erie Basin.

The great depth of erosion by the preglacial Cuyahoga river shows that the Tertiary river of the lake Erie basin had its course on a land surface which is now covered and raised, probably for the greater part from 200 to 400 feet, by the deposition of glacial and modified drift during the Ice age. The topographic irregularities of the preglacial Erie valley are thus largely enveloped by the drift, which forms a very level expanse beneath the shallow lake. The relationship of deep drift deposition on the valley lowland, while the contiguous uplands, as in the vicinity of Cleveland, bear little thickness (as 5 to 20 feet) of drift, is paralleled by the same conditions in the deep drift, mainly till, in large part 200 to 300 feet thick, in the valley of the Red river of the North, forming the vast flat plain that was covered by the glacial lake Agassiz, while the Cretaceous highland of the Pembina mountain, next west of the valley plain and glacial lake area, bears usually no more than from 5 or 10 to 25 or 50 feet of drift. The ice-sheet exercised a selective power to deposit much drift in certain valleys and lowlands within a few hundred miles of its outer limits, although on the adjacent hills, plateaus, and bluffs it parted with little drift, its work there being rather erosion than deposition.

Owing to the abundance of water in the seams and beds of stratified gravel and sand (modified drift) which occur in the lower half of the drift-sheet at Cleveland, the accompanying deposits of till in those parts of the well sections, perhaps less clayey and more sandy and softer to bore than the higher parts of the till, are apt to escape the attention of the workmen, who therefore probably report in some cases a larger amount of sand and gravel, and less till or clay, than is the actual character of the section. In the Standard Oil Company's well, at least, of which a detailed record is supplied by Newberry's report, the far greater part of all the section is clay (probably nearly all till). In that well (with the bluff above it) the till has a thickness, next below the Late Glacial delta sand, of 150 feet before coming to the first observed seam of modified drift; but in the lower part of the section a few beds of coarse gravel, contained in the till, indicate fluctuations of the glaciation in its early stages, with free drainage conditions, the altitude being greater than now and the lake area not yet depressed to be a closed basin.

Postglacial River Erosion in Cleveland and along the Bed of Lake Erie.

The map accompanying my previous paper, already referred to, shows very conspicuously the modern valley which the Cuyahoga river has cut through its Late Glacial delta and into the drift-sheet beneath. It was also observed in that paper that this recent erosion followed shortly after the glacial recession permitted an avenue of drainage from the Laurentian lakes area eastward by the Mohawk valley, as is known by the absence of any delta in the margin of lake Erie resulting from the Cuyahoga erosion since the lake attained its present form.

When the glacial retreat uncovered the Mohawk valley, this region was depressed toward the north and northeast, in comparison with its altitude today. But soon, while yet lakes Algonquin and Iroquois existed, held in by the waning ice-sheet on their northeast sides, the former being tributary to the latter by a large stream which I have called the river Erie, flowing in the course of the Saint Clair and Detroit rivers and along the bed of lake Erie, the country was moderately uplifted, with increasing extent of elevation from west to east. Thus the east end of the broad Erie river valley rose soon to such height that a lake began to be held in its shallow basin and grew in westward extent until it reached its present area, covering the channel of the river Erie, which appears to be represented by the deepest soundings of the lake. It also covered the alluvial and delta deposits of the formerly longer Cuyahoga river, tributary to the river Erie and the expanding lake Erie. The subsequent and most recent action of the Cuyahoga river has been to fill with alluvium the lower part of its modern gorge within the limits of the city of Cleveland, where it had been eroded somewhat below the present river and lake level.

ORIGIN AND AGE OF THE LAURENTIAN LAKES AND OF NIAGARA FALLS

BY WARREN UPHAM

The paper is printed in full in the American Geologist, vol. xviii, pp. 169–177, September, 1896.

GLACIAL FLOOD DEPOSITS IN CHENANGO VALLEY

BY ALBERT P. BRIGHAM

The paper is printed in full in this volume.

CORRELATION OF WARREN BEACHES WITH OUTLETS AND MORAINES IN SOUTHERN MICHIGAN

BY F. B. TAYLOR

This paper is printed in full in this volume.

NOTES ON THE GLACIAL SUCCESSION IN EASTERN MICHIGAN

BY F. B. TAYLOR

An abstract of this paper is printed in the American Geologist, vol. xviii, p. 234, October, 1896.

ORIGIN OF THE HIGH TERRACE DEPOSITS OF THE MONONGAHELA RIVER

BY I. C. WHITE

An abstract of this paper is printed in the American Geologist, vol. xviii, p. 227, October, 1896, and the paper in full is published in the December Geologist.

ORIGIN OF TOPOGRAPHIC FEATURES IN NORTH CAROLINA

BY COLLIER COBB

POST-CRETACEOUS GRADE-PLAINS IN SOUTHERN NEW ENGLAND

BY F. P. GULLIVER

A short abstract is printed in the American Geologist, vol. xviii, p. 231, October, 1896.

PRE-CAMBRIAN BASELEVELING IN THE NORTHWESTERN STATES

BY C. W. HALL

BASIC PITCHSTONE AND MUD ENCLOSURES OF THE TRIASSIC TRAP OF NEW ENGLAND

BY B. K. EMERSON

The paper is printed in full in this volume.

ORIGIN OF CONGLOMERATES OF WESTERN INDIANA

BY T. C. HOPKINS

[*Abstract*]

It would form an interesting chapter in geology to trace out the history of that widespread heavy bed of conglomerate occurring at the base of the Coal Measures and which ushered in the great coal-making period. Although the present paper deals only with that part of the bed which occurs in the state of Indiana, it has to that extent a bearing on the general question of the origin of conglomerates.

The conglomerate in Indiana forms a belt from half a mile to six miles or more in width, which extends from north of the middle of the state line on the west in an east of south direction to a point southwest of the middle of the state line on the south, and which passes in one direction into Illinois and in the other into Kentucky.

Like all the rocks in Indiana, the conglomerate has a general southwest dip. It is overlain by the productive Coal Measures which outcrop to the west, and underlain by the Lower Carboniferous limestones and the older Paleozoic rocks which outcrop to the east.

The entire thickness of the formation varies from 20 feet to more than 100 feet. Probably 90 per cent or more of this is a medium coarse-grained sandstone, the remainder being a conglomerate varying locally in the composition and size of its constituents. Occasionally the conglomerate is as much as 20 feet in thickness; more commonly only a few feet, sometimes but a few inches, and in some localities does not appear at all, being replaced by the sandstone.

The constituents vary in size from those no larger than wheat grains to some several inches in diameter. Some are hard, crystalline, white or milky quartz; others are of fossiliferous gray chert.

We should naturally look to a granitic or crystalline area for the quartz material, but the nearest localities are the Atlantic coast on the east, the upper lake region on the north and the Iron Mountain region of Missouri to the southwest, distant 200 miles or more in any direction. The transportation of so much coarse gravel such long distances without leaving a perceptible trail leads one to seek elsewhere for a source before going to great extremes to explain how the transporting was done.

The southwest dip causing the outcrop of the older rocks to the east suggests a careful scanning of these older rocks for the quartzitic material. Previous to my field work I did not regard these Paleozoic rocks as a possible source, but in the field I found great masses of chert conglomerate, sometimes 10 to 20 feet in thickness, the fragments being similar, even to the fossil contents, to the chert nodules and layers found in the Lower Carboniferous or Mississippian limestone. So plain is the resemblance that a simple field examination is sufficient to convince any one that such is their origin.

In a number of places crystallized quartz geodes, entire and rounded fragments of the same, are thickly intermingled with the rounded pebbles of quartz similar in its appearance to that in the geodes. The examination of a few such places is sufficient to raise the question, Why may not all these quartz pebbles have this source? This naturally leads to the inquiry as to whether they were sufficiently abundant to supply the material.

Persons who have seen only the few choice museum specimens of geodes would seriously question whether they were ever numerous enough to furnish the materials in the conglomerate, but a few days travel near the area of the Keokuk limestone east of the conglomerate would show that the supply is by no means small, and a summer's field work along this area would convince one (or at least did convince the writer) that whether such was the source or not, the supply of geodic quartz would be both a possible and probable source of the quartz pebbles in the conglomerate. If such should prove to be the case it would naturally lead to the more general question whether or not the supply in other localities might not be nearer the conglomerate beds than has been commonly supposed.

In brief, then, it may be said that field investigation shows that some of the conglomerate at the base of the Coal Measures in western Indiana has been derived from the segregated chert in the underlying limestone, and that at least some, probably a large part, has been derived from the quartz geodes of the Lower Carboniferous limestone. The question is raised whether all of the coarse materials of the conglomerate may not have thus originated.

Register of the Buffalo Meeting, 1896

The following Fellows were in attendance upon the session of the Society, Saturday evening, August 22:

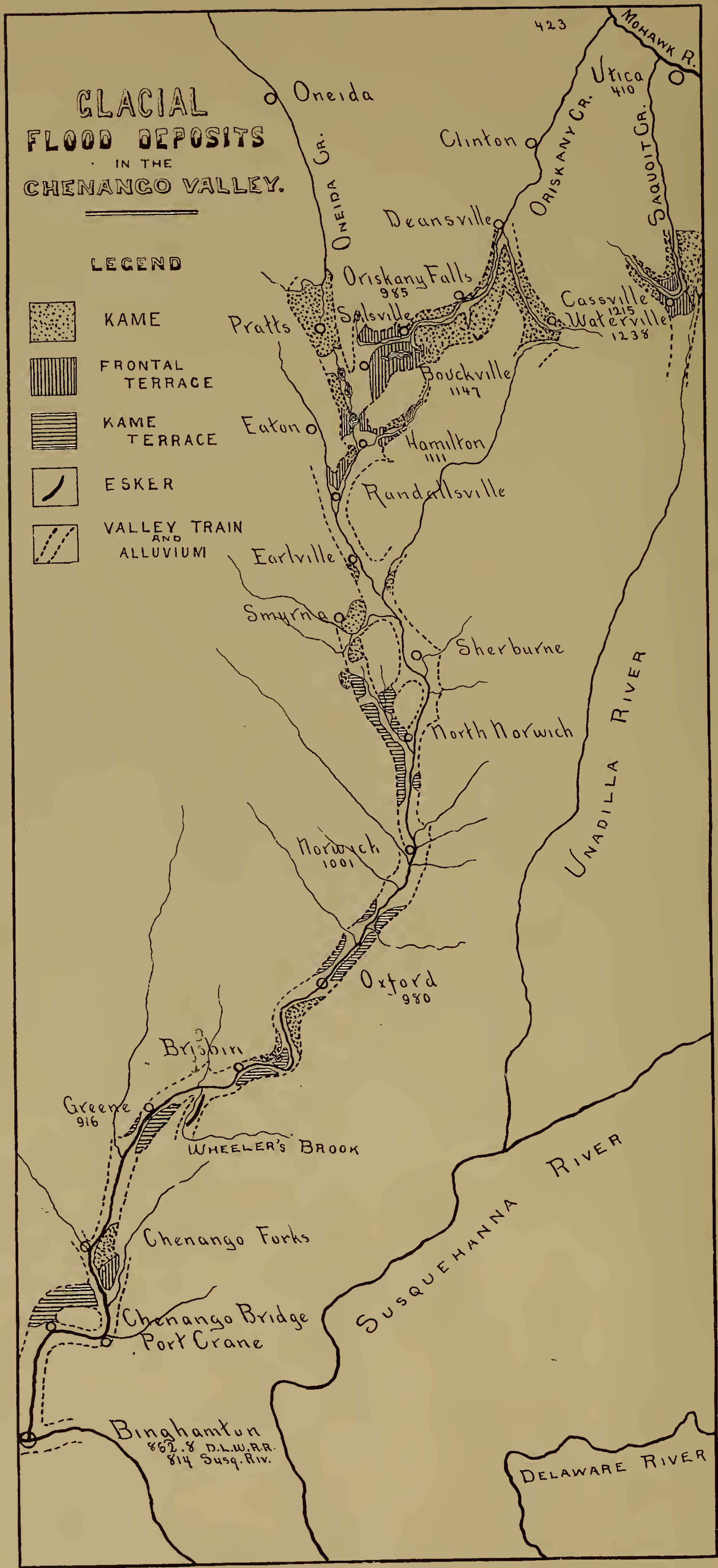
B. K. Emerson.
H. L. Fairchild.
C. W. Hall.
C. H. Hitchcock.
Arthur Hollick.
T. C. Hopkins.
Joseph Le Conte.
P. H. Mell.
W. H. Niles.
W. H. Norton.
Edward Orton.
W. N. Rice.
J. J. Stevenson.
F. B. Taylor.
M. E. Wadsworth.
I. C. White.

Present at the meeting of the Society, 16.

The following Fellows were in attendance upon the sessions of Section E, American Association for the Advancement of Science, the subsequent week:

A. P. Brigham.
Samuel Calvin.
E. W. Claypole.
E. D. Cope.
H. P. Cushing.
C. R. Eastman.
H. T. Fuller.
G. K. Gilbert.
James Hall.
E. O. Hovey.
H. C. Hovey.
E. E. Howell.
D. W. Langdon.
T. H. McBride.
W J McGee.
F. J. H. Merril.
F. H. Newell.
J. P. Smith.
J. W. Spencer.
J. E. Todd.
J. F. Whiteaves.
R. P. Whitfield.
H. S. Williams.
R. S. Woodward.
J. B. Woodworth.
A. A. Wright.
G. F. Wright.

Total attendance, 43.



GLACIAL FLOOD DEPOSITS IN CHENANGO VALLEY

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GLACIAL FLOOD DEPOSITS IN CHENANGO VALLEY

BY ALBERT PERRY BRIGHAM

(*Presented before the Society August 22, 1896*)

CONTENTS

INTRODUCTION.

It is designed in this paper to describe the character and distribution of those deposits in the Chenango valley which owe their form and structure, wholly or in part, to the waters of the melting glacier. Theoretic considerations will have but a limited place, and especially must any adequate reading of the glacial history of the region await the detailed study of parallel areas on the east and west. The upper course of Oriskany creek on the north is included in the study, the common valley of the divide near Bouckville being as spacious as farther down on either stream. The position of the water-parting is determined within certain limits by the disposition of the glacial flood materials. The neighboring cols at Pratts, Waterville, and Cassville are of a similar nature. Thence the north-flowing streams pass, by short, sharp descent, to the

Mohawk and Ontario waters, while the Chenango and Unadilla rivers reach the Susquehanna by a much longer and more gentle flow. The hill ranges, which alternate with the valleys, afford a type of topography exercising a strong influence on glacial action and products.* The altitudes of chief interest are: Mohawk valley at the mouth of Oriskany creek, 423 feet; Oriskany Falls, 985 feet; Bouckville, at the divide, 1,147 feet; Chenango Forks, 901 feet; Binghamton, Delaware, Lackawanna and Western railway, 862.8 feet; Binghamton, Susquehanna river, 814 feet. From the divide, the average descent northward is about 30 feet per mile, and southward about 5 feet per mile.

The kames in the vicinity of Oriskany Falls were described by Vanuxem.† In the paper to which reference is above made these deposits are noticed by Professor Chamberlin and correlated with the great morainic series to which they belong. He also refers briefly to the glacial accumulations at Chenango Forks, Greene, Oxford, North Norwich, and near Hamilton. Dr T. W. Harris has also given an account of the kames of the Oriskany valley.‡

Classification.

General Discussion.

The material will be described under the following heads: Kames, Eskers, Frontal Terraces, Kame Terraces, and Valley Trains. The terms kame, esker, and valley train have now come to have a well settled significance. For the glacio-fluvial terraces so abundant in a hill and valley region like central New York, we do not seem to have attained to the same harmony of usage. The term kame terrace is proposed by Professor Salisbury for a class of stagnant ice deposits made chiefly on the borders of valleys.§ Several paragraphs of definition and local description in the report cited could be transferred to similar deposits in the Chenango valley without material change. Gilbert also describes somewhat fully their mode of formation in his report on lake Bonneville,|| but designates them moraine terraces, and distinguishes them as lateral and frontal. In Professor Chamberlin's still earlier definition of morainic terraces,¶ to which Gilbert refers, the frontal type appears to be more especially described. In this paper the term kame terrace is restricted to the lateral variety, and frontal terrace is here applied to such shelf-

* Terminal Moraine of the Second Glacial Epoch. T. C. Chamberlin; 3d Ann. Rep. U. S. Geological Survey, pp. 344, 345.

† Geology of New York, Third Dist., p. 218.

‡ Am. Geologist, vol xiii, June, 1894, pp. 384-390.

§ Ann. Rep. Geol. Surv. of New Jersey, 1893, p. 156.

|| Lake Bonneville. G. K. Gilbert; Mon. I, U. S. Geological Survey, p. 82.

¶ Terminal Moraine of the Second Glacial Epoch; 3d Ann. Rep. U. S. Geological Survey, p. 304.

like bodies of stratified drift as are directly associated with the kame aggregations of the valley. It is believed that in some cases they were deposited in considerable bodies of water, rendering appropriate the term "delta terrace;" but the internal structure is not sufficiently revealed in all cases to warrant this, nor would the frontal deposits thus be distinguished from certain other deltas built into the flooded valley at the mouth of lateral streams. It should be observed that the frontal terrace has characters in common with the kame terrace, the sand plain, and the glacio-fluvial apron.*

KAMES.

Oriskany Valley area.—These kames occupy the Oriskany valley in a massive way for a distance of seven miles, from Deansville past Oriskany Falls to Solsville, where they graduate into the frontal terraces yet to be described. This great extension is due to the diagonal position of the valley in relation to the general ice movement. A longer section of the valley was thus brought within the east and west morainic belt of which the kames are a part, and earlier stagnation of the valley ice was induced at the same time. On the northwest side of the valley the kame belt is narrow, varying in width between one-fourth and one-half mile. Near Oriskany Falls it is absent, exposing extensive ledges of rocks of Helderberg and Oriskany age. The main body of the kames lies on the southeast side of the valley, from one to one and a half miles wide, and nearly cut into two masses south of Oriskany Falls, where a transverse passage was kept open by a subordinate ice-tongue springing from the principal ice-mass at the axis of the valley. The kames are of typical development adjacent to the stream, whose course is constricted and tortuous through the moraine from Solsville to Oriskany Falls, but broadens to a quarter of a mile, and runs quite directly from the latter place to Deansville. The relief is usually less sharp as one recedes from the stream, and not uncommonly toward the main valley wall the accumulations assume the form of massive shoulders of drift. They are thus brought into somewhat close relation with the kame terraces described in a later section of this paper. Individual knolls at Oriskany Falls have a height of 90 feet, and the main mass rises to 175 feet above the railway at the station. Individual knobs rise 25 to 50 feet higher, making a total relief of 225 feet. Below the present valley level the depth may be as much more, for the original trench is wide and the stream is crowded toward the northwest, where it has encountered a spur of limestone, over which it falls for about 15 feet. On the southeast for some distance the surface of the drift drops off to a broad shallow sag against the valley side. Far-

* The Great Ice Age. Geikie. Glacial Phenomena of North America. T. C. Chamberlin; p. 749.

ther north and around the end of the range that comes up between Oriskany Falls and Waterville the kame merges imperceptibly with the ground moraine rising above it.

Numerous sections show the usual discordant structure. Sometimes no trace of bedding appears, but the material is well water-worn, and till sections or scratched fragments are almost never found in this and the kame fillings of adjoining valleys except near the junction of the kame with the ground moraine of the hill slopes. The inclination of beds is commonly to the southwest, often at a high angle. The material for the most part has been carried from two to four miles from its sources, several Paleozoic outcrops being here crossed in rapid succession.

Dr Harris believes that the kames were formed at the edge of the ice, in a foot-lake which lay north of the col. I am led to question this as the precise mode of their origin. No doubt sluggish streams and irregular, temporary lakelets at the margin often received material which helped to make up the mass; but if a foot-lake of considerable proportions existed it was probably after the construction of the kames; nor does it seem possible that it could have discharged copiously or long at Bouckville, since the frail hills of kame upon whose flanks its waters must have risen do not afford evidence of its presence. Professor Chamberlin remarks that kames are associated with vigorous ice-action, and that hence they represent chiefly marginal glacio-fluvial deposition.* The case in hand is a particularly good illustration. The kames were formed at the border of a massive tongue of ice, and continually grew inward and northward, taking possession of the valley as the glacier vacated it. That the ice, though slowly receding, should still at times be active is evident when we remember the great depth and breadth of the Mohawk Valley depression. With a surface slope of but 30 feet to the mile, the ice would have been 1,400 feet thick over the site of Utica while the kames were forming at Oriskany Falls. Owing to the nearness of the Adirondacks, the slope and consequent depth of the ice may have been greater. In any case both the topography of the region and the great bulk of the kames show that the ice crowded down from the heights, filling the Mohawk basin to its rim about Oriskany Falls, and maintained a fluctuating margin there for a long period of time. It is quite possible that this single kame area contains as much rock debris as issues from the mouth of the Mississippi in a period of ten years.

Areas about Hamilton.—About three miles north of Hamilton, bordering the west side of the valley for a mile and a half, is a minor belt of kames of moderate relief, flanked by glacial ponds and a large swamp on the east and succeeded by a terrace southward. An ice-tongue which

* The Great Ice Age. Geikie. Glacial Phenomena of North America, p. 746.

may have been the joint product of the two valleys, which here converge from the north, left the kames on its western border and a frontal terrace by discharge at its southern end. Retiring, it left in its bed lakes and marshes, which, with the kames and terraces, form a vivid object-lesson in ice and water work.

A considerable assemblage of kames lies in a side valley two miles northeast of Hamilton. They have so nearly blockaded the valley that only a moderate amount of constructive work was needed for the embankment of the large Madison reservoir. The kames graduate into terraces on the border of the main valley.

West of Hamilton lies a belt of kames one mile long and a half mile in greatest width. The maximum altitude above the base is 108 feet, with decline southward, fading into the Randallsville terrace. The kame contours reach down to the valley floor. This fact, with other evidence, goes to show that no very deep or massive flood found this avenue of discharge during the closing stages of glaciation.

Areas farther southward.—Of these, but three are important. The first is at Smyrna, eleven miles south of Hamilton. West of Sherburne and of the Chenango river is a mass of Devonian beds, some miles in extent and 400 feet high, completely dissected out from the main plateau by river and glacial action. Smyrna lies in the lateral valley northwest of this block of strata. The creek which passes Smyrna from the northwest originally took a southeast course by North Norwich. It has now been diverted northward and enters the river above Sherburne, leaving a part of the ample valley south of Smyrna without a stream, but now traversed by the New York, Ontario and Western railway.* The kames at Smyrna lie in two groups. The first is crescent-shaped, bears the village on its southern end, and extends northward one and one-half miles, with maximum height of 90 feet. The second group is south of the town, on the east side of the valley, more compact in form and about a mile in extent. The elevations rise going southward to 140 feet, and the mass ceases abruptly in a broad, open valley. Another area lies south of Oxford. It will be seen by the map that the Chenango valley is almost free from all but valley train and alluvial accumulations from Randallsville to a point midway between Norwich and Oxford, a distance of twenty-five miles. The Oxford kames lie east of the river. They begin at one mile below Oxford and extend nearly two miles, with a width of one-half mile and

* South of Sherburne and west of the river is a second isolated mass, separated by a narrow gap from the first. The Delaware, Lackawanna and Western railway leaves the river at Sherburne, passes through this gap, and with the New York, Ontario and Western line reenters the river valley at North Norwich. It is a curious fact that two lines of railway should for several miles leave the perfectly open, main valley and follow a side course which is considerably choked with drift.

height of 80 to 110 feet, becoming bench-like at the south end. The rest have strong relief and much of the ground, unlike all other kame ground here described, is exceedingly bouldery, mainly with local, angular fragments up to two feet in size. The adjacent valley side is also very stony, in places nearly covered with boulders of a similar type, but is non-morainic in topography, the rock being but sparsely mantled with till. These bouldery hillsides extend to three miles above Oxford. Adjacent to the kames, the immediate valley of the river is nearly occupied with rolling gravel train, approaching the kame type of relief, again showing that there were no deep and powerful floods from the melting ice farther north to subdue the surface. Southward, in a broad bend west of the river, lies a stagnant ice deposit, surmounted westward by a narrow belt of kames which extends along the valley side to a point near Brisbin.

The remaining area is at Chenango Forks, and is the most important aggregation of these deposits south of Oriskany Falls. The valley is nearly filled for a distance of two miles above and below the entrance of the confluent stream from the west. The river is crowded over to the west side of the main valley, where it strikes a rock-bed. The main mass of the kames is 150 feet in height, and some accumulations are doubtless 50 feet higher on the hill slope. The relief is very strong, with steep knolls, deep kettles, and tumultuous interlockings of ridges. A great drift terrace, with a height of 40 to 50 feet, springs from the moraine and stretches southward for about two miles. Other kames occur in the course of the valley, but are small in extent or associated with kame terraces.

ESKERS.

Deposits of this nature are not common in the region here reviewed. Minor illustrations occur at the village of Deansville, in the Oriskany valley; in connection with the Oxford kame area by the valley side, and at Brisbin, on the riverward side of the kame terrace at that place. The only noteworthy esker lies in the valley of Wheelers brook, which enters the Chenango valley from the south, between Brisbin and Greene. The esker is east of Wheelers brook and east of the axis of the valley, whose breadth is here about one-fourth of a mile. The north end of the drift ridge is in the edge of the Chenango valley, whence its course is due south one-third of a mile, thence in a general south-southwest direction, with sufficient winding to give fitness to Professor Shaler's designation, "serpent kame." Its length is about one and one-fourth miles. It varies in height from 30 feet at the north end to 70 feet at a short distance, and after half a mile drops rapidly, varying between 15 and 40 feet, rising near its southern extremity to 54 feet. The lateral slopes vary from 20 to 32 degrees. The top in places is narrow and sharp, elsewhere rounded, and is occupied for nearly a half mile by the highway of the valley.* The surface is quite rough with boulderets, and a considerable talus of such material lies at the base of one of the steeper sections. The valley appears to be continuous with the course of another stream to the south, thus furnishing free outlet for the subglacial waters, which were the agent of deposition.

FRONTAL TERRACES.

The most important structures of this class are at Solsville, where they stretch away from the great kame moraine already described. They lie just north of the divide, so that, while their surfaces slope gently westward, the narrow path of Oriskany creek descends between, in the opposite direction. The kames on both sides graduate down into the terraces, which in turn are pitted in their upper portions, but smooth and uniform toward their distal extremities. The marginal slopes range from 20 to 25 degrees.

The northern terrace is nearly two miles long and varies from one-fourth to one-half mile in width. A short lateral valley from the north is graded up to its level both by ponding and silting and by intrusion of the waste from the main valley. Farther west the terrace pushes nearly across the valley of Oriskany creek, which here enters from the northwest. This headwater, like several others near by, has been pirated from the Chenango by the swifter northern streams. The terrace is here smooth and benched toward the main valley, but morainic in surface expression on the side looking up the tributary valley. Where the terrace springs from the moraine at Solsville its height is 70 feet. At the west end it is 45 feet. The difference is due to the gentle descent of its surface westward and the opposite fall of the course of the existing stream.

The southward terrace is nearly three miles in length and a mile in greatest width. A rather abrupt turn of the valley southward swung the current in that direction and prolonged this terrace beyond its companion. It also is 70 feet high where it joins the moraine, but descends more rapidly than the other, and terminates upon the divide with an altitude of 18 feet. Its frontal and terminal slopes at and south of Bouckville have an average inclination of 18 degrees and are decidedly lobate in form. Madison lake, three-fourths of a mile long, one-fourth of a mile wide, and said to be 75 feet deep, lies in an elongated kettle-hole in the body of this terrace. Its water-level is 16 feet above the ad-

* Some typical Eskers of southern New England. J. B. Woodworth; Proc. Boston Soc. Nat. Hist., vol xxvi, p. 215.

jacent Oriskany creek and about the same distance above the surface of a smaller pond with surface outflow near by. Into the latter it doubtless pours its surplus water through the intervening gravel. South of the lake the continuity of the plain is much broken, and we have deep and broad kettles and kames rising to, but not surmounting, the general level.

The material is course and bouldery in character and tumultuous in structure near the moraine, but surfaces are sufficiently worn by rolling to remove all glacial graving. Farther forward, sand and gravel replace the coarser matter and assume a definite structure. A well drilled 113 feet from the top of the northern terrace near the moraine found gravel and boulders to a depth of 75 feet, and sand from that point to the bottom. On the north margin of the south terrace exposures of the lower beds are frequent for more than a half mile. Fresh sections are so numerous as to demonstrate that the "foreset beds," as termed by Professor Davis, have unbroken continuity for 1,230 feet, well stratified sand and medium gravel beds inclining forward from 25 to 30 degrees. These beds, with the pronounced frontal slopes and lobes at Bouckville, appear to prove the existence of a water body into which the material was discharged, at least during the later stages of construction. The lake may have been marginal to a shrinking ice-tongue merely, or may have been more extended, filling the valley and prolonged southward. It has seemed possible to account for such a temporary lake by the stagnation and recession of the ice in this diagonal valley and the persistence of a strong current from the more direct Oneida valley acting as a dam at Pecksport.

Additional accumulations of this order lie between Pecksport and Hamilton, a deep glacial lake occupying most of the interval between the terraces. The easterly one is three-fourths by one-fourth of a mile in extent, 27 feet high at the south end, rising to 35 feet farther north. The surface is smooth, slopes slightly southward, but more rapidly toward the axis of the valley. The south end is strikingly lobate, with frontal slopes of 13 to 18 degrees. The material of the lobes is sand and gravel, rather fine. Northward we have abundant small boulders, gravel, and sand, one fresh section, coarsely stratified, showing southward inclination of 10 to 15 degrees.

The western terrace accords with the other in height and slope, is broader and longer, ends southward in no very characteristic way, and is somewhat interrupted by transverse depressions. It thus fails of the delta character shown by its companion, but is headed by a moderate assemblage of kames, which, in turn, the easterly terrace lacks. Between the kames and the terrace runs the foss often found in such situations.

Succeeding the kame area on the west of Hamilton is an interesting development of terrace at two levels. The kames grade into the higher one, which is a mile in length and three-fourths of a mile wide, reaching around by a single lobe toward the Eaton valley. The altitude is 50 feet, the top very smooth, and the eastern border kame-like. There are no fresh sections by which the structure can be determined. Midway the terrace is interrupted by a transverse non-erosion channel from northwest to southeast. A cross-section of the shallower portion toward the hillside shows a top width of 12 rods, bottom width of 6 rods, depth of 18 feet, and side slopes of 15 degrees. At the eastern margin it is slightly wider, the slopes steeper, but smooth as before, and cuts the terrace to its base. It extends across the terrace by a rather smooth curve. The presence of stagnant ice is a possible, but forced, explanation. It may be that after building the apron south of the channel the glacier retreated and made another frontal discharge, whose southern border was near and parallel to the northern face of the earlier one. Such proximity and parallelism would be surprising, but the northern concavity of the axial curve and the slightly lobate character of the slopes on the north side at least suggest it as a possible mode of origin.

The lower terrace drops 15 feet where it abuts upon the higher, or where, as should perhaps be said, the higher one is built out upon it. It stretches southward three-fourths of a mile, roughly triangular, projecting upon the broad floor made by the coalescence of the two valleys, but extending around to the west and north, the two terraces together forming a rude V at the south end of the inter-valley ridge which rises northward. The marginal slopes are constructional forms with gentle kame contours on the east, becoming somewhat lobate south and west. The surface is not pitted, the marginal slopes run from 12 to 18 degrees, and the height at the border is from 20 to 25 feet. A slight bench appears on the east side of the valley below Hamilton, at the higher level; also farther up and across Eaton valley, but in the latter case not at strictly accordant levels. The conditions here suggest comparison with those described by Russell, where mountain spurs project into the Malaspina glacier, producing melting and lake waters on either hand.* Similar terraces might be expected about the point north of Pecksport or at Chenango Forks, but do not occur.

Frontal terraces occur in a limited way above Hamilton in association with the Reservoir kames, and in a more extended manner reaching off from the kame area at Chenango Forks. The latter have not been sufficiently studied for careful description, but mention should be made of

*Second Expedition to Mount Saint Elias. I. C. Russell; 13th Ann. Rep. U. S. Geological Survey, p. 77.

an excellent illustration at Cassville, at the Sauquoit-Unadilla divide. The conditions are parallel to those at Solsville, and a railway cut at Richfield junction exposes a fine section of perhaps 60 feet in thickness, in which the "topset" and "foreset" beds are shown in great perfection.

KAME TERRACES.

These occur, as might be expected, in the gently sloping middle and lower Chenango valley. They extend much of the distance between Smyrna and Norwich. Three miles south of Smyrna the height is 36 feet, at North Norwich 70 to 75 feet, and somewhat greater at their termination, two miles north of Norwich. Sometimes the terrace is very narrow or disappears. At other points it blocks the greater part of the valley, as for two miles north of North Norwich, where we have accordant projections from both sides, so that there are gaps barely sufficient for the brook, alternating with lake beds of half a mile or more in extent. Viewed along the top, these accumulations are quite perfect benches; but so kame-like are their borders that the terrace character would hardly be suspected if seen only from the level of the stream. Sometimes a steep, straight, wall-like margin alternates with the kame border, depending upon the form of the ice against which or upon which the deposition takes place, as is set forth both by Gilbert and Salisbury in the passages cited. The materials range from sand to coarse gravel, much rounded and discordantly bedded. The presence of extensive deposits of this nature in this parallel valley and their absence from the main valley above and below Sherburne may be explained by the active flow of glacial ice there after it here became stagnant, for if the main valley were clear it is difficult to see how enough water could have coursed along the margin of the tongue between Smyrna and North Norwich to have done the work.

Other areas, which it is not necessary to describe minutely, occur about Warn pond, two miles above Brisbin; at Brisbin on the east and south, and extending past Greene on the east for several miles. The last forms a massive terrace 100 feet high, with some strong associated kames.

Two important areas remain. The first extends for four miles above Oxford. On the west the bench is narrow. On the east side there is a typical development, with a massive bench, as at the cemetery and the Soldiers' home, or with an approach to the kame form, as near Lyon brook. The south end of the mass at the Soldiers' home is distinctly lobate, the more southerly lobes lying toward the river and retreating *en echelon* toward the eastern valley side. Two excellent sections in these lobes fail to show foreset beds.

The last area extends from Chenango Bridge north and east three miles by the Delaware, Lakawanna and Western railway to the point where the railroad meets the river again, three miles north of Port Crane. This broad valley, which the river is believed to have occupied in preglacial time, is blocked with terrace-like deposits, broken by broad, shallow kettles, the tabular masses and low kame mounds rising to a common level. Here appears to have been a belt of stagnant ice with much melting and deposition, while the Port Crane valley was yet filled with a solid ice-stream. At the eastern end of this series of accumulations is a terrace corresponding to the frontal terrace springing from the Chenango Forks moraine.

VALLEY TRAIN.

General character.—No attempt is made to distinguish upon the map the valley train from the flood plain, lacustrine, and marsh deposits which are associated with it. The necessary sectional character of valley train growth is thus described by Professor Salisbury:*

"As the ice receded northward from the position of the moraine the waters arising from its melting coursed through those parts of the valley successively freed from ice. These waters deposited sand and gravel, especially just beyond the edge of the ice at each successive stage. Since the ice withdrew from south to north, the gravel just north of the moraine, or at least much of it, was deposited before that of the valley still farther north. This general relation holds up to the north line of the state and beyond. The valley gravel was largely deposited in sections, so to speak, commencing at the south."

The facts in the Chenango valley are quite in keeping with this description of the process. Especially, as we have seen, must we lay aside exaggerated notions of floods coursing with great depth and power and strewing materials throughout the valley. Tumultuous action could only have taken place for short distances as the ice receded, and the more, in view of the gentle declivity from Bouckville southward. It is to be remembered that the abundant, far traveled material in the lower valley had been transported mainly in a subglacial manner during a long period, and thus was ready to receive final distribution with short carriage by the issuing stream.

Lacustrine beds.—It is evident that at many, if not all, stages of valley filling lakes were larger, more numerous, or more continuous than now. Very many whose basins were shallow have been silted up, and all stages of the process are open to our inspection. This emphasis upon lacustrine conditions is required not only by the numerous small lacustrine plains,

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* Geol. Surv. of New Jersey, Ann. Rep., 1894, p. 22.

but by evidence from well-borings which will now be presented.* The wells in general are situated near the middle of the valley.

Rowlands Well, Hamilton.

	Feet.
Soil, fine gravel and sand	26
Fine, homogeneous blue clay, gravel stones only near bottom and rare	165
Quicksand	26
"Cement" sand—fine sand caked or partly consolidated	55
"Cement" gravel	4
	276

Maydole Well, Norwich.

Clay struck at 6 feet and continued to below 200 feet, except mixture of quicksand at about 100 feet, "black gravel" at bottom. Total 212

Lyon Foundry Well, Greene.

Cinders	6
Gravel	8
Clay and quicksand	80
Clay and gravel	1
Clay	8
Clay and gravel	2
Clay	12
Quicksand	7
Quicksand and gravel	10
Hard-pan	4
Conglomerate and quicksand	30
Rock	7
	175

Wells at Chenango Bridge.

Gravel	40 to 50
Sand and clay	125
	165 to 175

Port Dickinson Wells (3 *miles north of Binghamton*).

Two wells give—

Gravel	20
Clay with thin beds of gravel	155
	175

A third gives—

Gravel	15
Blue clay and quicksand to rock	185
	200

* The writer is indebted for well records to Messrs W. R. Rowlands, of New York ; H. A. Lyon, of Greene ; A. E. Race, of Norwich ; William C. and Stephen Shear, of Port Crane, and R. Shear, of Binghamton. The Messrs Shear are well-drillers of long experience.

Binghamton.

One mile north of Binghamton railroad station, rock at	160
Half a mile north of Binghamton railroad station, rock at	125
At Binghamton railroad station, rock at	70 to 75
Business part of Binghamton, rock at	50 to 60
Dairy Association well, Washington street near Chenango river, mostly gravel, some clay near the bottom, rock at	70
Patten well, Washington street near Court, sand and gravel to rock at	55

A quarter of a mile west of Washington street bridge the Susquehanna runs on a rock-bed, and other evidence is against the presence of a buried channel on either side. At the city water works, a short distance up the Susquehanna, rock occurs at 80 feet, and a half mile farther up four wells in the center of the valley reach rock at 60 feet.

Recapitulation.

Thus we have rock bottom at—

Hamilton, below	835
Norwich, below	789
Greene, at	748
Port Dickinson, at about	646
One mile north of Binghamton railroad station, at about	686
Half a mile north of Binghamton railroad station, at about	721
At Binghamton station, in the opening of Chenango valley, at about	771
Binghamton, business section	785
Binghamton, Susquehanna river bed, at	814

Thus the rock-bed of the valley progressively descends northward from Binghamton for several miles and probably much farther. The exception at Greene may be due to the position of the well, and deeper boring might show the descent to continue to Hamilton and the Mohawk valley.

The facts thus given have an important meaning for the history of drainage in this region. Preglacial northerly elevation would in part account for the deep cutting in the northern part of the valley, but would not explain the rapid shallowing at Binghamton. Some facts additional to those recorded above suggest the possibility of reversal of drainage during some period of its development. Definite judgment must be reserved for fuller studies, which are in progress and whose results it is hoped to present at an early day. It is evident that this history is needed for adequate discussion of the valley train and lacustrine beds. That lake waters occupied the valley in whole or in successive sections, for a long time, is clear. The deeper wells all give in general section beds of gravel of limited thickness, a few to 50 feet, underlain by almost massive clays from 120 to 165 feet. I am informed by one of the drillers above named that it is rare to find gravel or even sand commingled with these clays, sometimes 100 feet being drilled without gritty particles being noticed. When the course of the preglacial drainage shall be fairly made out, it will be possible to trace with some degree of definiteness the progress of deposition in the Chenango and the several associated valleys east and west, which must have witnessed much the same order of events. It is believed that differential northward depression has in any case been an important factor in the history of these accumulations.

All the deposits here passed in review, save perhaps the deeper filling of the valley, must belong to the later phases of glaciation in this region. The kame terraces, which are typical phenomena of recession, recur persistently from near Binghamton to Smyrna. The retirement was interrupted by important pauses, perhaps with episodes of readvance, about Chenango Forks and Oxford, as is evident from the kames and associated phenomena of those localities. From some sections of the main valley, as above Chenango forks and from North Norwich to Hamilton, the glacier retired continuously and rapidly. Above Chenango Bridge the river found its old course blockaded and took a new course by Port Crane, the railway still holding to the older and wider valley. The kames and frontal terraces from Randallsville past Hamilton give evidence of much ice and water action as we approach the principal moraine. The significance of the latter has already been set forth.

Summary.

1. The ice retired with relative though not absolute rapidity from the Chenango valley with several important pauses, but halted for massive and prolonged work at the southern rim of the Mohawk basin.

2. The easy southward gradient of the valley, more gentle then than now, favored stagnation and led to much making of kame terraces.

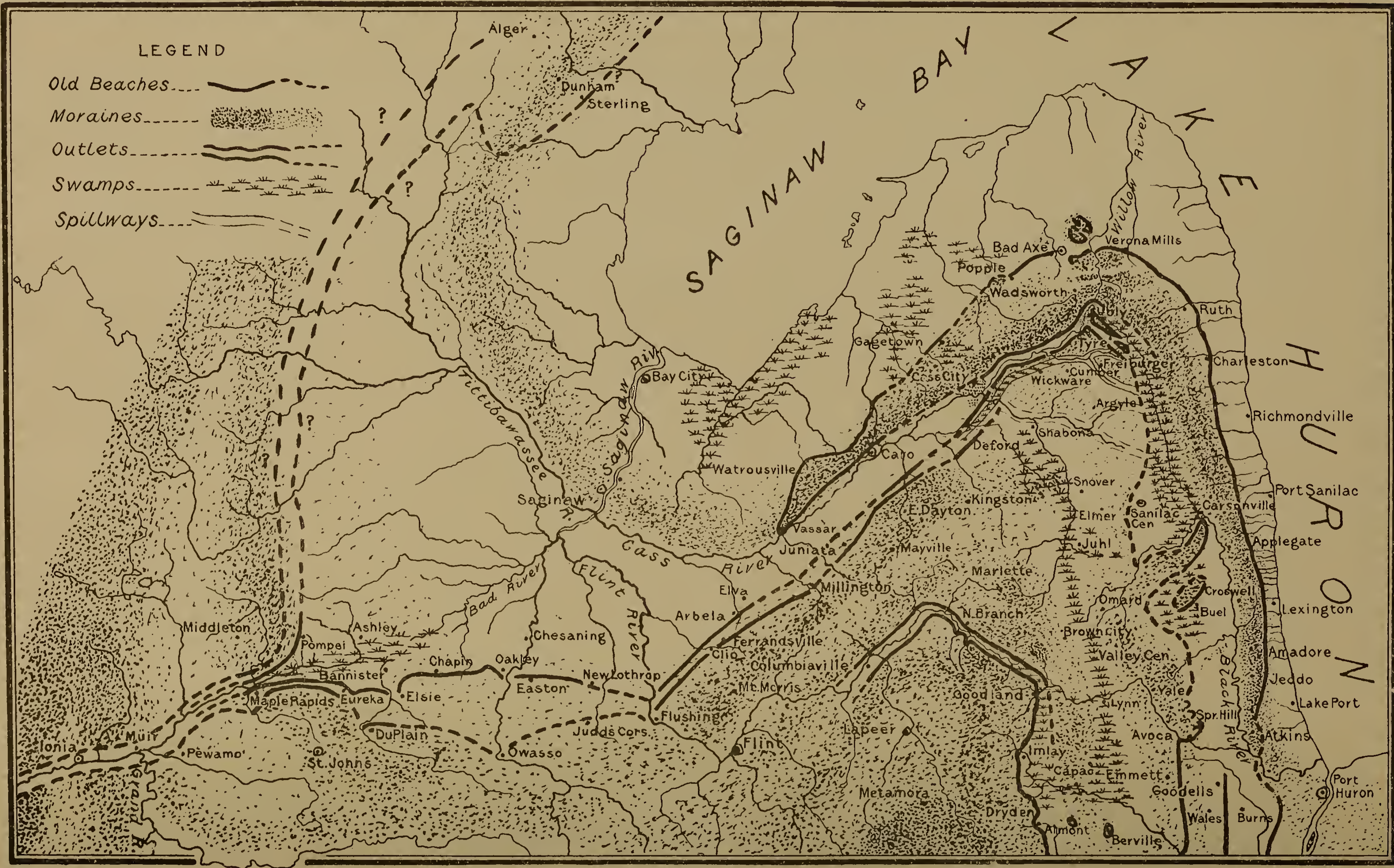
3. Such recession involved the presence of important ice-tongues, whose length, thickness, and duration would form a fruitful theme for further investigation.

4. The moraines are of the kame type and generally are fronted by terraces, some of which have true delta characters.

5. Eskers have small place among the aqueo-glacial structures of the region.

6. The facts are unfavorable to the existence of deep and powerful floods in the valley during the progress of melting, and an essentially sectional manner of valley train accumulation is accepted for this region.

7. Decided lacustrine conditions prevailed from near Binghamton to the head of the valley for a long period. No opinion is offered as to the precise structural and time relations of the deep clays to the other deposits described in this paper. It is believed that northern differential depression and preglacial conditions of drainage yet undetermined are important factors in the problem.



ERIE-HURON BEACHES IN SOUTHEASTERN MICHIGAN AND THEIR RELATED OUTLETS AND MORAINES

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CORRELATION OF ERIE-HURON BEACHES WITH OUTLETS AND MORAINES IN SOUTHEASTERN MICHIGAN

BY FRANK BURSLEY TAYLOR

(*Read before the Society August 22, 1896*)

CONTENTS

INTRODUCTION.

The object of this paper is to present an account of the work of the past season upon the moraines and abandoned beaches and outlets of the

" thumb " and the Saginaw valley in Michigan.* The " thumb " is that part of the state which projects northward between Saginaw bay on the west and the south end of lake Huron on the east.†

Our previous knowledge concerning the Pleistocene formations of these areas may be epitomized as follows :

Professor T. C. Chamberlin's map in his report on the " Terminal Moraine of the Second Glacial Epoch " ‡ shows the great Saginaw-Erie interlobate moraine of northeastern Indiana and southeastern Michigan projected hypothetically northward well toward the end of the thumb. Another great interlobate, which may be called the Saginaw-Michigan, is also shown on the extreme west of the Saginaw valley, but no other moraines are recorded within these areas. His latest map, issued in the recent edition of James Geikie's " Great Ice Age " (opposite page 727), shows only one additional moraine. It belongs to the Saginaw glacier, and lies mostly south of the valley, only a small part of it falling within the area here under consideration.

With respect to beaches, the only observations recorded are those of Dr J. W. Spencer.§ Beaches had been recognized at points farther south near Ypsilanti by Professor Alexander Winchell several years before,‖ but so far as known he did not trace any of them northward to the area here considered. Spencer had traced an extensive series of beaches in Ontario and had named the body of water that made them lake Warren, and later Warren water and Warren gulf, supposing it to have been marine.¶ He supposed this lake to extend almost without limit to the north and northeast and to overspread the basins of all the Great Lakes ; and he supposed further that the same waters had formerly stood at still higher levels, much higher than the highest beaches which he had traced continuously in Ontario. Beginning near the Ohio-Michigan state line west of Toledo, to which Gilbert had previously traced several beaches from Ohio,** Spencer followed four beaches northeastward to a line passing nearly due west from Port Huron. He found that the three lower beaches of this series corresponded very closely with three similar beaches

* After this paper was read at the Buffalo meeting, ten days more were spent exploring on the "thumb." A few additions have been made in consequence, and the interpretation of the phenomena has been slightly altered in one or two instances. This will explain some slight points of difference which appear between this print and the abstract published in the American Geologist for October, 1896, pp. 233 and 234.

† Mr G. K. Gilbert spent some time in this part of Michigan in the early part of June, but after working a few days on these beaches he was called east, and at his suggestion the work was taken up by the writer. Due acknowledgment is here made of the free use of Mr Gilbert's notes.

‡ Third Annual Report U. S. Geological Survey, 1881–1882 ; maps opposite pages 214 and 222.

§ "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer, Am. Jour. Sci., vol. xli, March, 1891.

‖ "Geology of Washtenaw County," by A. Winchell, 1881.

¶ Science, vol. xi, p. 49, Jan. 27, 1888 ; Proc. Am. Assoc. Adv. Sci., vol. xxxvii, 1888, pp. 198, 199.

** Geological Survey of Ohio, vol. 1, chap. xxi, 1871, by G. K. Gilbert, beginning at page 357.

which he had traced in Ontario. He therefore correlated the corresponding Michigan beaches with those in Ontario and applied the same names to them. Beginning with the highest, he called them the Ridgeway, Arkona and Forest beaches. Another higher beach in Michigan he called the Maumee. The Maumee and Ridgeway are almost certainly continuous with Gilbert's numbers 2 and 3 in Ohio, but southward connection has not yet been definitely established for Spencer's Arkona and Forest beaches. Before the time of Spencer's work, N. H. Winchell had named Gilbert's numbers 2 and 3 the Leipsic and Belmore ridges respectively, supposing them to be terminal moraines. These two names will be used here, but Spencer's names for the two lower beaches, the Arkona and Forest, will be retained.

Spencer also made a reconnoissance across the southern part of the Saginaw valley westward to Grand Rapids, and thence along the coast of lake Michigan to Chicago. He found beaches and terraces in the Saginaw valley which he correlated with those he had traced up from Ohio. His map shows the lower three of the four beaches passing northward around the end of the thumb to the Saginaw valley, while his Maumee beach is shown as turning west across the thumb at Imlay, leaving a large island to the northward; but the island and the beaches passing around the thumb are shown as hypothetical, for they were not actually traced. Only two beaches are shown by Spencer in the Saginaw valley. The upper one of these is made continuous with his Maumee, but it was certainly not traced continuously, as we shall see presently. Although Spencer traced two beaches into the long, deep trough of Maple and Grand rivers extending westward across central Michigan, he did not report the discovery of an old outlet. He called this valley the Pewamo channel, but regarded it as holding only a strait and not a flowing river. On the thumb the valley between the mainland and the hypothetical island was also taken to be a strait.

Topography.

Almost the entire region under consideration is heavily covered with glacial drift. Very few outcrops of the country rock occur except along the present lake shore and in the beds of some of the larger streams. On the thumb the coating of drift generally grows thicker inland. The great Saginaw-Erie interlobate moraine, which is so well developed farther south, extends only to the southern part of Lapeer county. One of its highest points, 1,200 or 1,300 feet above sealevel, a little to the southeast of Metamora, is the head of the interlobate, for at Dryden, nine miles east, and at Imlay and Lapeer, northeast and north, the level is much lower and the morainic deposit has lost its interlobate character. There is no true interlobate deposit anywhere on the thumb beyond the Metamora head. In the rest of the area here considered the ridges of the terminal moraines with intervening plains of ground moraine are developed for the most part in simple and regular forms. Three moraines lie beyond the Metamora head and bend around on the thumb from the Saint Clair valley on the east to the Saginaw valley on the west. They are best seen as three distinct individuals on the eastern slope between central Lapeer county and the south end of lake Huron.

All the moraines of this region show two distinct phases. In general the thumb has a smooth, flat surface, whether level or gently inclined, below a contour at approximately 200 feet above the lake. This feature was also noticed by Dr A. C. Lane, who joined the writer on an excursion from Bad Axe. This level, marking a distinct plane of change in the physical character of the moraines, corresponds in a general way with the upper limit of submergence. Where they project above it the tops of the moraines present the usual irregular rolling surface, but where they lie below it they lose nearly all their irregular features, and in fact are so subdued that they are often with difficulty distinguished from the ground moraine. These water-laid moraines are faint as topographic features, but they mark the former positions of the ice-front just as surely as the hilly land-laid form.

With respect to the configuration of the moraines, the Saginaw valley is the exact antithesis of the thumb. On the latter the advancing ice was held back by the obstructing high land, and its front line formed a reentrant angle at each stage concave to the southwest. In the former the ice pushed farther forward over the low ground along the main axis of the valley, presenting a convex front to the southwest and forming one of the most perfect and symmetrical ice-lobes to be found anywhere on the continent. Southwest of the head of Saginaw bay the first moraine back from the lake shore is water-laid and very greatly subdued, but it rises gradually northeastward toward the end of the thumb and finally emerges into a land-laid moraine of the normal rugged type. The other moraines, though less submerged, do the same, and they all emerge also in the higher region west and northwest of the bay. In the low belt southwest of Port Huron these moraines also become water-laid as they descend toward their apexes near Port Huron, at Detroit, and at Toledo.

The glacial waters that gathered in the Erie, Huron, and Ontario basins during the retreat of the ice-sheet underwent many changes. These changes are now so far worked out that it has become possible, and also very necessary, to have some clear and orderly way of designating them. In falling from their highest level to the present level of lake Erie the glacial waters changed the place of their outlet four or five times. At each change they paused for a time, sufficient to make a distinct beach or shoreline. In applying names we might treat the several pauses as so many stages of one lake, but the waters changed their levels, outlets, shapes, and sizes and shifted their areas so extensively as the ice-sheet withdrew that it seems better to consider each stage that had a separate outlet as an independent lake to which a separate name should be applied. Then the whole series may be called by a descriptive or locative name, such as the Erie-Huron lakes.*

The first stage of the glacial waters does not fall within the area here considered, and has not been a special object of study by the writer, but a brief account of it is given below in order to present a complete chronology of the changes from the first to the last of the Erie-Huron glacial lakes. This lake was named Maumee lake by Dryer in 1888.†

Lake Maumee.

VAN WERT BEACH.

This beach extends from the head of the outlet four miles east of Fort Wayne through Van Wert, Ohio, to Findlay, where it ends on the front of the Defiance moraine. It extends (as Winchell's Hicksville ridge) also from the head of the outlet northeast through Hicksville and Bryan, Ohio, to Adrian, Michigan, where it probably ends against the same moraine. The correlation of the beach with the moraine at Adrian corresponding to that established at Findlay by Leverett has not yet been made by observation, but appears to be a matter of safe inference. The beach is nearly horizontal throughout, with an altitude varying between 775 and 795 feet above sealevel, or 200 to 220 feet above lake Erie.

FORT WAYNE OUTLET.

This extends from a point four miles east of Fort Wayne westward through the city, and thence southwest to the Wabash river, near Huntington. It is generally a mile or more wide, and toward its head is partly floored with gravel now covered with peat. Near Huntington it crosses a sill of limestone. The possible continuance of this channel as the course of a partial outlet during the next stage will be discussed below.

DEFIANCE MORAINE.

This is the first terminal moraine east of Fort Wayne, and passes in a great curve convex to the west from Findlay through Defiance to Adrian.

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*Mr Upham used the name lake Erie-Huron in 1891 to designate the same waters as are here called the Erie-Huron lakes. See "Glacial Lakes in Canada," by Warren Upham, Bull. Geol. Soc. Am., vol. 2, 1891, p. 259.

† Sixteenth Report of the State Geologist of Indiana, 1888, "Geology of Allen County," by Charles R. Dryer, M. D., pp. 107–126. This lake was also called Western Superior glacial lake by Upham in 1893. See Minnesota Geological Survey, Twenty-second Ann. Rep., 1893, p. 62.

Through most of this distance it is water-laid, and hence somewhat subdued in expression. Maumee lake was bounded by the ice-front when it stood at this moraine and by the Van Wert beach. Its features were originally worked out by Gilbert and N. H. Winchell, with later researches by Leverett in Ohio and Dryer in Indiana.*

Lake (unnamed).

LEIPSIC BEACH.

Spencer called the highest beach traced by him toward the northeast from Adrian the Maumee beach. It appears to be almost certain, however, that it is identical with Gilbert's beach number 2, and also with Winchell's Leipsic ridge in Ohio.†

Gravel ridges were found at Berville and Imlay corresponding to Spencer's altitudes of his Maumee beach at those places. The Maumee or Leipsic beach is generally quite light in its formation, appearing almost solely as a small, simple and rather narrow ridge of sand and fine gravel. At Berville it appears as a small gravel island in a wide expanse of shallows. The ridge at this place is apparently a wave-wrought modification of a gravelly kame, and its identity as a beach seems to the writer to be not entirely free from doubt. Going west eight miles past Smiths Corners and Hopkins road to Almont, two or three more low gravelly islands with the tops fashioned into forms resembling beaches were passed. At the latter place the ground is higher, and from near there a gravelly beach was followed northward about seven miles along the rough eastward front of the upland almost continuously to Imlay. Spencer's levelled altitudes make the ridges 817 feet above sealevel at Berville and 849 at Imlay. The difference of 32 feet in altitude seems to cast some doubt on the unity of the ridges as one beach at both places, but if the two ridges are really independent beaches both ought to be found at Almont on the same slope, for the slope at that place is favorably situated for receiving a record of wave action at both elevations, the altitude of its base being 800 feet above sealevel. Almont station is 807 feet, and two miles north of Almont the beach has an altitude of about 825 feet.‡ This seems to show that the difference between Berville and Imlay is nearly all due to

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*Gilbert and Dryer as above. N. H. Winchell in Proc. Am. Assoc. Adv. Sci., vol. xxi, 1872, pp. 171–179; Geological Survey of Ohio, vol. II, 1874, pp. 56, 431–433. F. Leverett, Am. Jour. Sci., vol. xliii, pp. 281–297, April, 1892.

†Spencer says this beach is identical with Gilbert's beach number 1 in Ohio ("High Level Shores," etcetera, p. 208), but in this opinion he is probably mistaken, for there is every reason to suppose that if the Defiance moraine stops the Van Wert beach at Findlay, Ohio, as Leverett finds, the outlet of that time being through Fort Wayne, then the same moraine ought to stop the same beach on the north side of the Maumee valley. The junction of the beach and moraine is near Adrian, Michigan.

‡Altitudes all determined by aneroid barometer from railroad stations or from the lake shore.

northward ascent, the change of plane westward being slight. South of Imlay for about two miles the ridge lies a quarter to a half a mile west of the main road. In the northwest part of the town there is a gravel pit dug out of a spit of this beach. Three-fourths of a mile north, on the west side of the road and north of Belle river, the beach may be seen on a hillside as a long, narrow, curving, spit ridge pointing southwest, very lightly but perfectly formed.

IMLAY OUTLET.

Northward the beach passes into a valley and grows fainter and more fragmentary, the last well formed piece being near Goodland church and cemetery, about five miles north of Imlay. The church is on a bluff overlooking a wide summit swamp which extends about four miles north and nine northwest to North Branch. The beach at the church has an altitude of about 850 feet and the swamp below is 25 to 30 feet lower. Mill creek drains this part of the swamp toward the northeast, while from Imlay the Belle river drains it southeast past Capac. This summit level has an altitude of about 820 feet. From Goodland church the beach extends in fine form a quarter of a mile northward along the crest of the bluff. On the north side of an interrupting ravine it reappears once more as a faint gravel ridge, but beyond that fades away on a stony slope and could not be again identified. About four miles north of the church at a saw-mill a road crosses the north summit level of the swamp to the east side without a bridge and at an altitude of about 810 feet. Northwest of this the swamp is drained by Cedar river, which, after passing about four miles beyond North Branch, turns to the southwest to join Flint river above Columbiaville. From the mill to North Branch the old channel was crossed nine times. Most of the way it is about one-third of a mile wide. The adjoining lands are mostly high, rolling, stony, morainic hills, with occasional kames. On the north side and back from the channel somewhat more than a mile is an immense kame-moraine hill, the highest point for many miles around and standing quite alone. Its summit is 1,050 to 1,060 feet above the sea. The slopes of this hill were examined by the writer and also by Mr Gilbert and were found to show no trace of submergence. Mr Gilbert also crossed the channel three or four times in its upper part, but did not see the faint Leipsic beach at the church nor the gravelly floor, which is better developed, however, toward North Branch. This outlet does not give evidence of a very rapid or powerfully flowing current, if the sediments remaining on its bottom are taken as an indication, for it is floored mainly by sandy beds of gravel and not by boulders and cobbles, as is the case with the Tyre-Ubly outlet, to be described later. The floor gravels are fragmentary, for the modern Cedar river has cut away a considerable part of the original deposit, especially in the northern part of the channel, but low terraces of this material are found nearly all along the sides, ranging from five to six feet above the center of the swamp at the saw-mill to fifteen or more above the present stream toward North Branch. In only a few places in the lower part is the bordering bank steep enough to suggest cutting by the current. The present bottom level of the channel one mile south of North Branch is about 795 feet above sealevel and at Columbiaville about 770 feet. Below North Branch the old stream floor widens out gradually, until at Columbiaville and two miles below it is about a mile wide, and Flint river is depressed in it from 20 to 25 feet. In the city of Flint, 18 miles farther southwest, there are extensive gravels at 740 to 750 feet that may belong to the old outlet river, but their relations were not fully determined.

It seems plain enough from the relation of the Maumee or Leipsic beach that this deep channel was the outlet, or at least one outlet, for this lake. But there are a few doubtful points which will have to be cleared up by further observations before it can be affirmed that this channel carried all the overflow. It has been supposed hitherto that the Leipsic beach as well as the Vant Wert connects with the Fort Wayne outlet, and that the level of the lake fell on account of cutting down in the outlet channel. This is a possibility, but the Leipsic beach seems a little low for such a relation. While this beach has not been traced continuously from Ohio to the Imlay channel in Michigan, the land features in the interval are so simple that the grounds for the inferred identity of Gilbert's beach number 2 (Leipsic) and Spencer's Maumee seem quite clear.

The comparative magnitudes of the Fort Wayne and Imlay channels present another difficulty. The former averages a mile or more in width, while the latter is only a third to a half mile wide. If this means that the volumes of the rivers were of like comparative magnitudes it would seem plain that the Imlay outlet did not carry the whole overflow of the lake. The discharge may have been divided between Fort Wayne and Imlay during the time of the Leipsic beach. None of the several observers in the Ohio and Indiana areas have reported more than two beaches above the Belmore. If the Leipsic beach connects only with the Fort Wayne outlet and Spencer's Maumee beach only with the Imlay, the two beaches being independent, there ought to be three beaches above the Belmore in the basin of lake Maumee. The reported presence of only two, coupled with the narrowness of the Imlay channel, seems to confirm the supposition of the divided overflow. Further observations will have to be made before it can be known whether the Leipsic beach does in fact connect with both outlets.

TOLEDO AND DETROIT MORAINES.

Parallel with the channel on its north side is a rugged, well marked moraine covering the space between the channel and Marlette and Brown City and extending southward nearly to Capac. This moraine marks the position of the ice-front in the early part—probably the first half—of the activity of this outlet, and extends south-southwest in very much subdued form to its apex at Toledo. Southwest from Capac it is nearly all waterlaid, but its influence on the minor drainage is well marked.

It appears that when the ice-front retreated from this moraine to the next or Detroit moraine it did not open a new outlet, but the same one continued to serve. Excepting a tract near Yale, the Detroit moraine is also nearly all water-laid and greatly subdued, but it shows the same kind of influence on the minor drainage as the Toledo moraine. The Detroit moraine was not clearly made out in its course across the thumb. It seems to fade away on the flat plain north of Yale, although it is probably represented by some of the high, isolated kames or kame-moraines that lie in that direction. The probable course of this moraine will be referred to again in connection with swamps that cross the summit of the thumb.

Lake Whittlesey.*

BELMORE BEACH.

According to Spencer, his Ridgeway beach is identical with Gilbert's beach number 3 in Ohio, and this is the same as Winchell's Belmore ridge. The most northerly point of Spencer's tracing is two miles east of Emmet, where the altitude is 770 feet. From this point it was followed north and then east past Spring hill, two miles northeast of Avoca, where its altitude is about the same. It is a strong and well formed beach and is easily followed to this point. At Spring hill it culminates in a great blunt spit of gravel compounded of many beach ridges laid up one against the other. The head of the spit projects toward the northeast, is about 40 rods wide, and at its front stands about 15 feet above the flats to the east and 10 feet above those to the northwest. Two more fragments of this beach were found within three miles northwest from

* Named after Colonel Charles Whittlesey, a member of the first geological survey of Ohio and one of the earliest explorers of the old shorelines in that state. See a volume entitled "Fugitive Essays," by Charles Whittlesey, 1852, pp. 179–191 (reprinted from Am. Jour. Sci. for July, 1850); also biographical sketch by A. Winchell. Am. Geol., vol. iv, November, 1889, p. 257 *et seq.*

the spit, both gravelly projecting points. Mr Gilbert also traced this beach from Emmet to Spring hill. North of the spit there is a stretch of 10 miles or more of very flat land on which no beach was seen. Four miles west of Croswell, a faint shoreline was found along the base of high ground about a quarter of a mile north of the corner at Buel, altitude about 780 feet. Again, on the east slope of a kame-ridge three and one-quarter miles west of Applegate is perhaps the best developed beach seen in the Black River valley north of Spring hill. Its altitude is about 770 feet. It is a low ridge of sandy fine gravel facing east over flats 30 to 40 feet lower, and three to five miles wide. At a point two and a half miles west and one mile north of Applegate the same faint beach was found at the same height, and it was found again on a slope six miles west and one south. There is also a very faint mark at the same height on the north slope of this kame ridge, facing north over Elk creek and the great Black River swamp. Mr Gilbert crossed just north of this region from Carsonville to Sanilac Center, and went thence southwest through Laurel to Brown City, but saw no shorelines nor outlet channels. Along Black river from Carsonville southward toward Applegate is an extensive gravel plain 30 to 35 feet below the beach. At the cemetery, two miles south of Carsonville, the valley at the level of the beach is narrowed somewhat where it passes between the high moraine east of Black river and the kame ridge which lies along the south side of Elk creek. From the narrows the Black river swamp extends northward over the summit to Cass river at Tyre and Ubly, a distance of 30 miles. In this stretch no beach or certain water-mark was found. The Belmore beach had therefore to be given up without having definitely established its connection by continuous tracing with any outlet channel. The faint fragments near Buel and Applegate are the only ones found north of Spring hill that could be supposed to belong to this beach. Nevertheless it is clearly the correlative of the Tyre-Ubly outlet described next below.

TYRE-UBLY OUTLET.

The Black river swamp passes over the col to the head of Cass river about two miles east of Ubly. A low gravel bank on the west side and midchannel bars on the crossing east of Ubly indicate that the water was at least 10 or 12 feet deep on the col. This is now about 790 feet above sealevel. The old waterlevel is therefore about 800 feet. On this crossing the swamp is nearly a mile and a half wide. The main channel passes northwest from the col to a point about a mile north of Ubly, where it becomes much narrower, scarcely more than half a mile, and makes a sharp bend to the southwest, in which direction it continues 17 miles to its terminus, about a mile east of Cass City. Ubly is on the floor of the channel, on the east side, one mile south of the bend. Two other smaller branch outlet channels cross cols about two miles east and southeast of Tyre. At this place they unite and pass thence as one channel close to Ubly on the south, and join the Ubly channel at a point a mile or more below the latter place. Tyre is about four miles southeast of Ubly and is also on the channel floor. Both channels possess distinct characters of water-courses. The Tyre channel is a bouldery swamp for some distance above the town, and at the station there is scarcely any covering over the underlying sandstone. The strata are bare in many places and the thin soil is very gravelly and stony. The Ubly channel is floored almost entirely with beds of gravel above the junction of the branches. Boulders are numerous in some places, as on the east side a little below the bend, one mile north of Ubly. The gravels were observed at several places to be at least four or five feet deep. Below the bend the width of the channel increases to three-fourths of a mile to a mile, and keeps this width to Cass City. From the junction the floor of the channel is covered with great numbers of boulders for most of the distance down to its lower end. The bouldery floor, nearly a mile wide, is well displayed at Holbrook, about half way down from Ubly. The floor a mile and a half east of Cass City has an altitude of about 730 feet. In its present attitude the floor descends about 70 feet from the col east of Ubly to Cass City, about 22 miles, but the descent of the water surface was probably somewhat less.

Cass City is built upon a gravel plain about two miles long east-and-west and nearly a mile wide, which from its position strongly suggests that it may be a delta of the outlet of lake Whittlesey. Its top level is about 750 feet above sealevel or 20 to 25 feet above the old channel bottom. There appeared to be a fragment of the same plain on the south side of the river also, as though the original deposit had been cut in two.

PORT HURON-SAGINAW MORAINE.

The contemporary position of the ice-front with respect to this outlet is very clearly marked. The last land-laid moraine of the Huron lobe of the ice-sheet lies close to the east side of Black river all the way northward from a point six or eight miles northwest of Port Huron. Where the Black River swamp is wide the main crest of the moraine is sometimes four or five miles from the river, but it is usually half that distance or less. The moraine is usually dual or triple in form, with two or three crests or ridges running roughly parallel half a mile to a mile and a half apart, the western one being the highest. Toward Ubly the moraine trends northwest, and at a point about three miles northeast of Ubly it meets the contemporary moraine of the Saginaw lobe coming from the southwest, and the two form a sharply defined angle of 75 degrees. The high ridges of the two moraines do not unite, but are cleft just in the angle. A small brook, the head-waters of Willow river, drains a part of the gravelly channel bed at the extreme north angle of the bend and carries its waters away north through the narrow gap to lake Huron, near Grindstone City. This cleft probably marks the entrance of a small glacial tributary to the great outlet river flowing from the ice-sheet when its front rested close by on the main moraine. The bend of the channel is exactly in the angle of the two moraines, but the narrowest point is half a mile farther west. The crest of the Saginaw moraine from the bend to Cass City is 80 to 100 feet or more above the channel floor, and the channel runs close along its foot all the way. The inner angle of the bend is held by a high, steep hill of drift with many boulders. It is the northwest end of a lower ridge, which seems to belong to the eastern or Huron lobe of the ice-sheet. This hill has been cut away to some extent on its north and west sides, leaving many boulders at its base. The base of the moraine opposite is also quite steep, apparently from the same cause. The hill in the angle evidently once extended a little farther to the northwest. Southwest of Tyre morainic ridges mostly of moderate height trend in a general east-and-west course. One of these lying next south of the Tyre branch is high at its west end, like the one north of Ubly, and appears at one time to have stood in much the same relation to the river. It stands in the angle where the Tyre channel turns southwest into the main channel.

The Tyre branch was apparently opened before the Ubly, and the former served as an outlet while the ice-front of the Huron lobe still rested on the morainic ridge which now separates the two branches. A later retreat of a mile or two by this lobe left an open space close along the ice-front in the new position, and this became the Ubly branch. After the Ubly branch opened the volume of discharge by the Tyre channel must have been largely decreased, but the level of the lake was probably not lowered much, for the heads of both branches are nearly at the same level. Judging from the comparative magnitude of the moraine between the channels and the later main moraine, it seems certain that the early activity of the Tyre channel must have been quite short as compared with the later period of their combined activity. In no other instance known to the writer is the relation of a great ice-dam and the outlet of the waters which it retained so close or so clearly and unmistakably shown. Ten miles north of Ubly the surface of the thumb begins a gradual descent of 200 feet to lake Huron. The circumstances in this case are such that there can be no possible doubt as to the place of the ice-front while this outlet was active. It was not over a mile or two from Ubly, and the outlet river from the col to Cass City flowed close along the foot of the ice-front. This position of the outlet was a natural consequence of the fact that that ice-front was retreating northward down a slope which happened to be the lowest part of the rim of the lake. For this reason the outlet hugged the receding ice-front and changed its place as fast as lower points of escape were uncovered.

By following the course of the Saginaw moraine to the southwest, curving back to the north on the west side of the valley, and the course of the Port Huron moraine to the southeast, curving back to the northeast in Ontario, we find the exact position of the great ice-dam in the basins of Saginaw bay and the south arm of lake Huron. It only remains to locate the contemporary ice-front in the eastern part of the Erie basin to know the exact boundaries of lake Whittlesey.

CUMBER SPILLWAY.

South of the Tyre branch and the united channels below and separated from them by a morainic ridge only a mile to two miles wide is an open valley which passes about a mile north of the villages of Freiburger, Cumber, and Wickware. The lower part of it near Cass City is a swamp, which we may call the Stone Wall swamp. This swamp is several miles long and in many ways resembles the greater outlets here described, but is somewhat narrower. It looked at first like an old outlet that might have had an importance in the lake history comparable with that of the Tyre-Ubly channel, and it was so regarded until the upper part was seen later. It was found in the end, however, to be another channel, with much the same history as the early history of the Tyre branch channel described above; that is, it was a spillway open only a short time during an active period of glacial recession, and soon abandoned for the newly opened Tyre and Ubly channels. The first activity of the Tyre branch itself was probably as a spillway, its function as part of the more permanent outlet beginning only when the Ubly channel had opened also.

The Cumber spillway lies close to the Tyre-Ubly channel on its south side throughout its whole length, and extends past Cass City about four miles on the southeast and appears to fade away on the plain north of Deford. The south branch of Cass river crosses it southeast of Cass City. Its altitude at its mouth is about the same as that of the Tyre-Ubly channel. The morainic ridge between the Cumber and Tyre-Ubly channels is 40 to 70 feet high, but at one point half way down the channel this ridge is broken, and through this break a creek drains the upper part of the spillway channel into Cass river at Holbrook.

The lower part, four miles east of Cass City, is a wet peat bog a little less than half a mile wide, with marl beneath. Extending for a considerable distance on a winding course through this part is the famous "stone wall," a remarkable ridge of boulders, low and narrow, generally only nine or ten feet wide. Locally it is supposed by some to be a work of prehistoric man, and the marl which lies just below the surface among the stones is supposed to be the crumbled mortar of the original wall. This wall is said to extend ten miles or more, but was seen in only two places by the writer. In some respects it resembles ice-beaches formed on the shores of small lakes, but this explanation seems unsatisfactory here and no better one has been suggested so far. The general course of the wall in this part is parallel with the ice-front. In its upper part the spillway valley grows narrower and divides into divergent head branches, with small swampy patches here and there. Its floor is slightly uneven, somewhat stony and sandy, but does not show effects of a flowing river in a marked way. One branch comes in south of Freiburger and passes northwest of this place to join the others. Two or three branches are crossed between Freiburger and Tyre, and one of them, the most northerly, appears to open out of the upper part of the south branch of the Tyre channel. The head branches of the Cumber spillway seem to show that it was a smaller and more temporary affair even than the early Tyre channel, and it seems clear that it does not, as at first supposed on seeing only its lower part, mark the outlet for a distinct lake stage with a corresponding beach. Instead of this, it was probably one of several temporary spillways that carried off the water, or a part of it, while the ice-front was in active retreat from its previous position at the Detroit moraine. It is doubtful whether the Cumber spillway ever carried off more than a fraction of the whole overflow of the lake, and this probably for only a comparatively short time.

There is another river valley about ten miles south from Tyre draining westward from the crest of the thumb. It is a branch of Cass river that flows westward about two miles south of Argyle and a mile north of Shabbona. Near Argyle it has two branches, one coming from the east and another from the southeast. The first has a small creek in it and its valley is from 10 to 15 feet deep and from 400 to 500 feet wide. The second is as large, but is swampy and carries only a small spring rill. Both stream beds put together, however, appeared to fall far short of sufficient capacity to carry the whole overflow. The valley is larger and deeper toward Shabbona and its floor is well covered with boulders. It seems too large for the present stream, although it is not greatly out of proportion. This valley may have been a spillway for a small part of the overflow for a short time, but it lacks the characters of the abandoned bed of a great outlet river. The present drainage divide on this part of the thumb is five or six miles east of Argyle. The two small streams are said to come from swamps on the divide, but their heads were not visited. There was probably a time when the overflow was escaping by two or three of the spillways at once, for the Cumber and Tyre channels were undoubtedly active together before the Ubly channel opened, and the Cumber and Argyle may also have been active together before that. In the finally established outlet of this period the Tyre and Ubly channels were both active as head branches of one outlet stream.

SUMMIT SWAMPS.

Between the Argyle valley and the Toledo moraine at Marlette and Brown City is a wide stretch of flat country with many swamps and few uneven features. The water divide of the thumb passes across this region from the north-northeast toward Brown City. A north-and-south swamp passes five miles east of Marlette at an altitude of about 810 feet. It extends south many miles, passing west of Omard, east of Brown City, through Valley Center and Lynn to Capac. Its summit level was not determined, but lies a few miles southeast of Marlette. Northward it extends down the course of Nettle creek west of Juhl and Elmer and Snover. Its north end was not seen. There are two or three swamps coming from the east into this one across the summit level of the thumb, but none of them, so far as seen, show the characters of abandoned river courses. They have no banks; the bordering lands are low and slope into the swamps at very low angles, nor were any bouldery or gravelly floors observed in them. In short, although there are a number of summit swamps, no plausible indication of a course of overflow was found between the Argyle valley on the north and the Imlay outlet on the south. The great north-and-south swamp referred to seems to be the trough between the Toledo and Detroit moraines, although the latter on this part of the thumb is but poorly developed as a surface feature. The general level on the divide is approximately 820 to 830 feet. In some places long stretches of it are so flat that it is conceivable that the overflowing water might have passed over it in a very thin sheet many miles wide, to be gathered into narrower, distinct channels only on the western slope, but no such channels were found, unless, indeed, the Argyle valley served in this way. Such a condition, however, could have lasted only a very short time at most, for any channel bed once begun would speedily eat its way back across the divide.

The long north-and-south swamp looked very favorable at first for the course of an outlet, but it probably never served as such unless as a very temporary spillway after or during the fall of Leipsic beach stage. At a point about half way from Elmer to Shabbona, Nettle creek and the swamp pass between morainic knobs 30 to 50 feet high. Toward the west from these knobs the country around East Dayton and Mayville is higher and rugged. These hills are the beginning of the second moraine in the Saginaw valley, lying next south of the Saginaw moraine, and seem to be the complement of the Detroit moraine on the east side of the thumb. When the ice still rested on the hills west of Kingston the valley of Cass river to the north was entirely buried under the ice. So that if the long swamp ever served the lake of the Leipsic beach stage as an outlet it must have turned away toward the southwest somewhere west of Elmer to reach the valley of Flint river. The Toledo moraine seems to cross the intervening space; but its relief in that part is rather low and there are many swampy tracts between the swells of drift. The general level is near 840 feet, but no evidence of an outlet channel across it was found. These facts, taken with the absence of channel characters in the long swamp itself, seem to show that, while it may have held water as a lagoon during the time of the Detroit moraine, the long swamp probably did not serve as a full-volume or a long-time outlet, but it may have served briefly as a spillway when the ice-front first withdrew from the hills at East Dayton.

Lake (unnamed).

ARKONA BEACH.

The lake marked by the Arkona beach is left for the present unnamed pending further investigation. This beach is possibly the same as the upper member of Gilbert's beach number 4, in western Ohio, and his upper Crittenden, extending eastward into western New York. According to Spencer, it occurs near Goodells at 697 feet, and extends in an almost perfectly horizontal position as far southward as the Ohio line. A gravelly tract was found on the plain one mile northeast of Spring hill by Mr Gilbert at an altitude of about 745 feet, but it seems hardly possible that this can belong to the Arkona, for it would require a sudden rise of 48 feet in less than eight miles. Going directly east from these gravels across Black river, Mr Gilbert found gravels at about 715 feet, which is approximately the level of the valley floor close to the bank of the river, and also a ridge of sand at 755 feet on the west face of the Port Huron moraine east of the river. The latter had the appearance of a littoral ridge, but was not found farther north. This sand probably corresponds in time of origin with the gravels at 745 feet on the west side, but they do not appear to be clearly correlated with any beach. No other observations were made either by Mr Gilbert or the writer that indicate positively the identification of the Arkona beach north of Goodells.

SPILLWAYS NORTH OF THE TYRE-UBLY OUTLET.

The course of this beach northward and the place of the outlet to which it is related are problems for future investigation. According to Spencer it is a weakly developed beach. The writer's observation at Goodells, between Burns and Wales, and at two or three other points farther south corroborate this statement. It would be expected, therefore, that its outlet would be less strongly marked than those related to the more strongly developed Leipsic and Belmore beaches. The facts which seem to have a bearing on the question of the probable course of this beach and the place of its outlet are these: The Leipsic beach was traced directly into the Imlay outlet; between this outlet and the Tyre-Ubly channel there is no well developed outlet channel that might have served for the lake during the time of the strongly developed Belmore beach, and between the Leipsic and Belmore beaches there is no other well developed beach. On this ground the inference seems plain that the Tyre-Ubly channel was the outlet of lake Whittlesey. Further, the Belmore beach was traced far enough north toward the Tyre-Ubly channel to furnish good reason to believe on this ground also that it does, in fact, connect with that channel. The Arkona beach lies below the Belmore, and hence if it had an independent outlet the place of that outlet must have been farther north than the Tyre-Ubly channel, but this beach has not been found on the eastern face of the Port Huron moraine nor on the western face of the Saginaw moraine. It seems certain, therefore, that this beach must be related to an outlet across the thumb and not pass around the end as a continuous mark of static waters. If the outlet for both the Arkona and the Belmore stages was by way of the Tyre-Ubly channel, then the independent existence of the former beach must have been due to a change of attitude, the outlet being lowered relatively to the region south of it, or the region to the south being relatively elevated while the outlet remained unchanged. Unless one of these alternatives be true, it would seem necessary to suppose either that the outlet was farther north or that this beach passed around the thumb. The country between Ubly and Verona Mills and Bad Axe is mostly high, rough, morainic ground, with low swampy tracts between the hills. Two open but rather crooked courses pass through from east to west, the first one about four miles north of Ubly and close by Wadsworth. It has a swampy floor and is comparatively narrow. At one place, four miles north of Ubly, it is well paved with boulders. The width in that part is about 70 or 80 rods, and the altitude of the floor about 785 or 790 feet above sealevel. This way might easily have been left open while the ice-front still stood on the hills immediately to the north of it, but this relation would not last long, for the ice-front had already receded from its most permanent halting place on the main moraine which lies between Wadsworth and Ubly. Farther north, less than a mile south of Verona Mills, a somewhat wider swampy valley passes through. This might also have served briefly. The eastern slope of the Port Huron moraine was closely examined at many different places northward from Port Huron both by Mr Gilbert and the writer, but no sign of the Arkona beach was found. If either of these channels north of the Tyre-Ubly was the outlet for the lake at the Arkona stage it must have been after the ice-front had retreated a little from the main Port Huron moraine, so as to leave a long narrow sound along its east side between the main moraine ridge and the ice-front through which the water could pass northward to these cross-valleys. This might well occur while the ice-front still rested on the high hills at Verona Mills. Such an adjustment, however, would certainly be short lived, in this respect agreeing with the faintly developed beach. Even this supposition, however, does not remove the difficulty without supposing in addition a considerable local depression of the Ubly-Verona Mills region before the making of the Arkona beach and after the fall of lake Whittlesey, for the cross-valleys north of the Ubly channel are very little lower than he Ubly channel itself. These spillways are probably later than the Arkona beach, and were probably scoured out by very temporary overflows immediately preceding lake Warren. The critical ground was so thoroughly examined that there is not much doubt that the Arkona beach does not extend around the end of the thumb, but connects somewhere with an outlet across it.

Lake Warren.

FOREST BEACH.

This beach is possibly the same as the lower member of Gilbert's beach number 4, in western Ohio, and his lower Crittenden beach in western New York. Spencer's last place of identification and measurement is at a point five miles west of Port Huron, where its altitude is 665 feet. Gilbert recognized this beach at several localities on the eastern slope of the Port Huron moraine between Atkins on the south and a point west of Richmondville on the north, a distance of about 35 miles. The following facts are taken from his notes: Atkins is five miles east of the Spring Hill spit (Belmore beach) and about ten miles northwest of Port Huron. One mile north of Atkins the Forest beach has an altitude of about 700 feet;* three miles farther north, 695 feet; west of Lake Port, 697 feet; east of Amadore, 695 feet, and between Carsonville and Port Sanilac, 720 feet. The writer joined Mr Gilbert in an excursion from Carsonville, when the beach was found three miles northeast at about 730 feet, and about five miles west of Richmondville, eight or ten miles farther north, at about 740 feet. North of these places the writer found this beach again at Charleston at about 740 feet; one mile east of Ruth at about 750 feet, and from a point about three miles east of Verona Mills it was traced continuously along the front of the hills, passing about a mile to the north of Verona Mills to Bad Axe, and thence six miles southwest to Popple, a total distance of about 15 miles. Its altitude in this stretch is about 775 feet. Northeast of Bad Axe there was an island, or perhaps two lying close together, the extreme point of land being about five miles north-northeast of the town. Between the island and the mainland is a short valley with a bouldery, swampy bottom about a mile wide. It is not improbable that there was a very brief time during the last lingering of the ice-front on the island when this valley held a flowing outlet. The descent of the water through this passage would hardly be more than two or three feet at the most, and at the next step of retreat a clear way was opened around the north side of the island. All the east-west valleys north of the Tyre-Ubly channel show a possibility of service as temporary outlets. Their positions point to this and a few specific evidences suggest it; but none of them show the strong characters of an outlet long used.

Continuing southwest, the Forest beach was found at Gagetown at about 765 feet. From a point six miles north of Caro it was traced south to a point two miles west of that town. Again, from a point two miles north of Watrousville it was traced five or six miles southwest into Vassar, altitude about 715 feet. On the hill in Vassar, near the water-tower and a little to the south and west of it, is the extreme tip end of a long narrow peninsula projecting toward the southwest from Gagetown and Cass City. From Vassar the beach turns back to the northeast along the inner side of the peninsula. It is not generally so well formed in this inner stretch, but was found on the east slope north of Vassar, at Watrousville, at Caro, and somewhat doubtfully at Cass City. The long peninsula is formed by the unsubmerged crest of the Saginaw moraine coming down from the northeast. The Cass River valley behind the peninsula formed a bay 25 miles long and only seven or eight miles wide at Vassar and having its head a little above Cass City. About two miles southeast of the latter place, on the south side of the river, or rather on the point be-

* The discrepance between this measurement and the next three is probably attributable to the aneroid, for the general slope of the Warren plane is southward.

tween the two branches of the river, the Forest beach is well formed at an altitude of about 765 feet. From this point it extends southwest in almost a straight line to the Flint river, a few miles north of Flushing. Much of this littoral belt is duney, and the beach could not be distinctly made out at some places. It was recognized on some kames about four miles south of Cass City, southeast of Caro, six miles south of Caro, somewhat doubtfully near Juniata station and two and a half miles west of Millington, and thence pretty continuously past Elva and Arbela and Clio nearly to the bank of Flint river, about five miles north of Flushing. Its altitude two miles west of Clio is about 700 feet. The beach trends thence about due west past New Lothrop and Easton, 710 feet; Oakley, 700 feet; Chapin, 700 to 710 feet; Elsie, 700 feet, and past Eureka to Maple Rapids, which is well within the head of the Pewamo channel. The beach is particularly distinct and well formed at Easton, Chapin, Elsie, and Eureka. It is a continuous gravel ridge almost the entire distance, and many miles of it are used for roadways. The country is very open and it is easily followed. The altitudes of points west of Chapin were not very satisfactorily determined, but as nearly as can now be stated the Forest beach at Maple Rapids has an approximate height of 680 feet above sealevel. This beach was found well developed also on the north side of the channel opposite Maple Rapids, and was traced thence northeast, curving around toward the north as far as Pompei. Spencer took this beach at Chapin to be his Ridgeway (Belmore), and he gives its height there as 760 feet (barometric). The writer's measurement was made from Chesaning, about 10 miles northeast of Chapin, as a base and under favorable conditions. The altitude given also agrees closely with measurements made to the eastward on other days. The col at the head of the Pewamo channel is said by Spencer to be not over 680 feet above sealevel or 100 above lake Huron. The col is a summit swamp passing from Bad river to Maple river between Ashley and Bannister.

In its physical appearance the Forest beach is in one respect unique. So far as seen by Mr Gilbert and the writer, this beach is nearly always dual in form. It generally presents two beautifully formed beach ridges, the crest of one being always eight or ten feet below that of the other. When the slope is very gentle the two ridges are sometimes nearly a mile apart. On steeper slopes the dual phase sometimes fails. East of Ruth the slope is very gradual and the ridges are a mile apart, the lower one being represented in this case by a belt of fine sand scarcely over a foot high. In the above list of localities and altitudes all the measurements refer to the upper ridge. This character of the beach was a great aid in its recognition. The double line is quite distinct at Charleston, east of

Verona Mills, southwest of Bad Axe, southeast of Cass City, west of Clio, and at Easton.

The Forest beach, in common with the others of the Erie-Huron beaches, has some very characteristic qualities when compared with the younger, much stronger Algonquin and Nipissing beaches below. It is represented almost entirely by gravelly or sandy wave-built ridges and more or less wave-distributed, sandy, delta deposits. It scarcely ever takes the form of a cut terrace, and hence seldom has anything like an old sea cliff behind it. Spits are seldom found more than a few yards in length, the one at Spring hill being quite exceptional. Only at the extreme end of the thumb northeast of Bad Axe, where the slope was steep, and in a similar situation along much of the moraine front from Gagetown southwest to Vassar was there any appearance of wave-cutting. As Tarr has found for these same beaches in western New York, the prevailing features are wave-built and not wave-cut.* At many places the Forest beach is well formed where it has not been fed by delta deposits, and it was hard at first to see from what source the material was derived. On closer examination, however, it was found that it had been washed up from the old lake bottom just below and in front of the ridges. There were some places where this belt was a little flatter than the general slope and a little more stony, showing the abstraction of some of its finer surface parts. The sand and gravel was evidently loosened and stirred up by the breaking of the waves on the shallow bottom and the forward motion carried them up the slope and added them to the beach ridge.

The prevailing composition of the Forest beach is sandy gravel, generally of a yellowish-brown color to a depth of several feet, showing considerable oxidation and decay. More or less gravel is almost always present, but sand is generally a large constituent. The pebbles are usually not large and are not thoroughly rounded. Scattered through the beach almost everywhere are fragments of chert, very light in weight and porous from the solution and loss of their calcareous parts.

In the vicinity of Verona Mills, where the Forest beach passes around the end of the thumb, the morainic hills are high and quite steep. Several of their tops reach altitudes of about 860 to 865 feet above the sea, or 85 or 90 feet above the Forest beach. Beyond these hills and below the Forest beach the plain stretches away east and north and west, sloping gradually down to the lake. The outer slopes of the highest parts were pretty thoroughly examined, but no sign of a beach, nor any other indication of static waters was found above the Forest beach. A week

* "Geological History of the Chautauqua Grape Belt," by R. S. Tarr, Bull. 109, Cornell Uni. Agri. Exp. Sta., January, 1896.

was spent in this search and in mapping the glacial topography, chiefly of the interesting region west of Verona Mills and between this place and Ubly, covering the angle of the two ice-lobes. From the results of this work it seems clear that no shoreline above the Forest passes around the thumb from the south, nor does any beach above the Forest in the Saginaw valley extend northeast around the thumb. Search was also made on the western slope of the Saginaw moraine southwest from a point six miles north of Caro over most of the interval to Vassar without finding any beach above the Forest. If the same vertical interval between the beaches existed at Verona Mills as on the line west from Port Huron, the Arkona beach should be found midway up the hillsides.

PEWAMO OUTLET.

This is one of the most magnificent old outlet channels to be seen anywhere in the lake region; but with the exception of the facts gathered at and about Maple Rapids, as already mentioned, and a few unconnected observations in the vicinity of Pewamo, Ionia, and the city of Grand Rapids, no close study of it was made. The channel is about 50 miles long, with a floor three-fourths of a mile to a little over a mile wide descending westward a foot or less per mile, and from Ionia down the bordering lands are mostly rugged morainic hills which rise from the channel bed rapidly to between 200 and 300 feet above it. On an excursion out of Ionia with Mr E. H. Mudge, of that place, several of the features described by him in a recent paper were seen, including gravel bars that seem to indicate a westward flowing current.* More of the same kind were seen on the east side above Muir. A well marked terrace skirts the valley on both sides—at Ionia at about 750 feet above sealevel, or about 100 feet above the channel floor. This was seen from the train nearly all along to Grand Rapids. On the south side at Ionia it appeared to be the remains of an old river floor at that level. There is also a lower terrace sometimes appearing at 10 or 15 feet. In the northern part of the city at Grand Rapids a great gravel ridge, apparently a spit built out across a small valley's mouth by waves running toward the north, stands just back of the Detroit, Grand Haven and Milwaukee railroad station, its summit being at about 746 feet. In the Saginaw valley there is a beach called the Du Plain, which lies above the Forest, but neither the Forest nor the Du Plain beaches were certainly identified below Maple Rapids, and it is not known what relation they had to the terraces in the Pewamo channel or to lake Chicago in the Michigan

*"Central Michigan and the Post-Glacial Submergence," by E. H. Mudge, Am. Jour. Sci., vol. l, December, 1895.

basin.* Several questions suggested by the features of this outlet will have to await further investigation.

CORRELATED MORAINES.

The Saginaw moraine bends gracefully around the west side of the bay and extends north-northeast parallel with the shore to the Au Sable river, but after crossing this to the north side it turns to the northwest. From Harrisville and Alcona another high rugged moraine runs away to the northwest, rising gradually. This is the Alcona moraine, and from a point six or eight miles north of Alpena another moraine runs up along the shore in the same direction and is called the Hagenville moraine.† Leverett has worked out the moraines that border the south side of lake Erie and has carried his explorations into western New York.‡ The wide interval between his Cleveland and Hamburg moraines suggests the presence of another unidentified member between these two, but taking his series as it now stands, the Lockport moraine in New York corresponds to the Alcona moraine in Michigan and was contemporary with it. If Leverett's series omits one, then his Lockport moraine would be the correlative of the Hagenville moraine of Michigan. One or the other of these Michigan moraines with the Lockport or the Albion moraine of western New York probably held up the last stage of lake Warren. The northward ends of the Forest beach, however, have not yet been determined either in Michigan or in Ontario, but while definite correlation has not been made with any moraine in the Huron basin, many observations made by the writer in the north in recent years seem to show that none of the Erie-Huron beaches extend beyond the central part of lake Huron. None of them reach to the Michigan or Superior basins nor to Mackinac straits or the shores of the North channel.

LAKE SAGINAW.

DU PLAIN BEACH.

When the ice-front stood at the Port Huron-Saginaw moraine and the Tyre-Ubly outlet was in operation, that part of the Saginaw valley which lay in front of the ice and below some col, probably in the western part

* Lake Chicago is a name recently suggested by Mr Frank Leverett for the glacial waters that filled a large part of the Michigan basin during the retreat of the ice-sheet. It occupied that basin from the time of the first ponding at the south end until the ice withdrew from the straits of Mackinac and allowed the waters east and west to come to one level. During most of its existence this lake received the discharge of the Erie-Huron waters which passed thence to the Mississippi through the Chicago outlet. Three beaches of this lake have been recognized, all leading to the Chicago outlet. This name has been approved by most of the other observers particularly interested in this area, including Professors Chamberlin and Salisbury and Mr Upham.

† See "Glacial Succession in Eastern Michigan." Abstract in Am. Geol, Oct., 1896, p. 234.

‡ "On the Correlation of New York Moraines with Raised Beaches of Lake Erie," by F. Leverett, Am. Jour. Sci., vol. l, July, 1895.

of the Pewamo channel, was occupied by a lake. From a point three or four miles east and southeast of Cass City a beach was found extending toward the southwest substantially parallel with the Forest and generally within at most a mile or two to the south. This is called the Du Plain beach, and it marks the shore of lake Saginaw. In some places it is a very conspicuous gravel ridge and is followed many miles by "ridge roads." It is of this character for much of the way from Clio northeast through Ferrandsville nearly to Millington, but in many places between Cass City and Clio it is so duney that it is hard to follow. It is well formed again on the east side of Flint river about two miles north of Flushing. Thence west the land is very flat, and the beach was not found for a number of miles. It is well formed again at Du Plain with a spit, and from near Eureka it was followed in fragments into the Pewamo channel to a point two or three miles southwest of Maple Rapids. It is particularly well formed about a mile east of the latter place. Throughout nearly all its course it lies from 20 to 30 feet above the Forest beach, but the vertical interval seems to increase somewhat toward Maple Rapids.

DURATION AND RELATIONS.

The duration of lake Saginaw and its relation to the other lakes of that time remains problematical. Whether it existed only during the third stage (lake Whittlesey), or also during the fourth stage (Arkona beach), or only during the latter, cannot now be said; nor is its relation to lake Chicago apparent. It is possible that the Du Plain beach is the contemporary of the Arkona, lake Saginaw having previously stood for a time at a lower level, but, so far as the two beaches are known to the writer, the Du Plain seems to be stronger than the Arkona. If it was a depression of the north end of the thumb that caused the making of the Arkona beach, then lake Saginaw might have had its relative level raised by the same movement. If such depression did not effect the Chicago outlet the current in the Pewamo channel might also have been so reduced that it would seem more like a strait than a river. Lake Chicago would still be separated from lake Saginaw, however, by a strait 50 miles long and only one to two miles wide. At any rate, it would appear that the depth of water in the channel must have been decreased, and hence the velocity of the current through it increased when the waters fell from the Du Plain to the Forest level. More observations, however, are needed before reliable conclusions on these points can be reached.

Deformations.

The deformations of the beaches described in this paper are not so marked as in some other areas, but they show some notable peculiarities.

Spencer found them all substantially horizontal from the Ohio line nearly up to Port Huron, but west of this place they all begin to rise northward. The profile on an east-and-west line from Imlay to Port Huron shows the following heights for the several beaches: Leipsic beach at Imlay, 849 feet; Belmore beach near Summit, 770 feet; Arkona beach near Goodells, 697 feet; Forest beach five miles west of Port Huron, 665 feet, and lake Huron, 581 feet. On a north-and-south line from Imlay through Ubly and Verona Mills, crossing the heads of the outlets, the heights are as follows: Leipsic beach at Imlay, 849 feet; Belmore on col east of Ubly, 800 feet; Arkona, not known; Forest one mile north of Verona Mills, 775 feet, and lake Huron, 581 feet. On the east-and-west line the vertical intervals between the beaches are, in descending order, 79, 73, 32, and 84 feet, while on the north-and-south line they are approximately 50 feet for the first, 25 feet for the second and third combined, and 195 feet for the last. The second and third combined on the east-and-west line are about 105 feet. On the north-and-south line the distances are about 50 miles for the first, 7 miles for the second and third combined, and 16 miles for the last. On the east-and-west line the distances are 16, 5, 4½, and 6 miles. In its horizontal part the Leipsic beach from Ypsilanti to Fort Wayne averages (from Spencer and Gilbert's measurements) about 785 feet altitude, so that its level at Imlay represents a northward rise of something like 60 feet from Ypsilanti or some point north of there. Treating the other beaches in the same way, we find that the Belmore rises about 35 feet to Emmet from horizontality somewhere north of Ypsilanti and about 67 feet in all to the col at Ubly, and that the Forest, which seems to be horizontal to Port Huron, rises thence 110 feet to Verona Mills.

The supposition of a local northward uplift springing from some point north of Ypsilanti and occurring after all the beaches were made does not account for all the facts. It might account for the deformation of the Leipsic and Belmore beaches, but not so clearly for the two below. If the axis of a low local anticlinal uplift were west of Imlay and its strike ran about northeast and southwest, the Leipsic beach, lying the farther west, would rise upon its flank sooner, while the Belmore would begin to rise at a point farther north, producing substantially the effect found; but from what little is known of the Arkona, it seems improbable that this idea applies to it, and it obviously fails for the Forest. It seems clear that there was a subsidence affecting the north end of the thumb some time after the Belmore beach and before the Forest. It is not known how this may have been related to the Arkona. The Forest beach rises from near Port Huron gradually and with fair uniformity for some distance, but more rapidly in the last ten miles toward Verona Mills, apparently indicating an uplift at the latter place after the formation of the beach. The Forest beach appears to show scarcely any deformation on east-and-west lines, except possibly a slight descent near Maple Rapids, but the amount is, in fact, so small that with the measurements made by aneroid it is not worth while to attempt close analysis. The Forest beach at Verona Mills is only seven miles north of the bend of the Tyre-Ubly channel and 25 feet below it. West of Port Huron the Forest beach is about 105 feet below the Belmore, and the Arkona beach lies between. The cross-valleys north of the Ubly channel are at altitudes midway between the col east of Ubly and the Forest beach near Verona Mills, so that if any of them served as the outlet for the Arkona stage, we must suppose a much sharper post-Warren uplift northward from Ubly than that which affected the region farther south. A sharper rise does appear there, as just pointed out, but it is much too little to explain the facts by the simple supposition of a local tilt. There seems to be no escape from the conclusion that in the Ubly-Verona Mills region there was a depression after the Belmore beach and a reelevation after the Forest. If this depression was great enough, the Arkona stage may have used the Tyre-Ubly channel as its outlet and the scour in the cross-valleys to the north might then be ascribed to the flow of very temporary waters as the lake fell from the Arkona to the Forest level. This seems to be the most plausible conclusion, but sufficient data are not now at hand for a more definite statement.

Nomenclature.

The sources of the particular names of beaches, outlets, lakes, and moraines used in this paper are mostly obvious or have been made sufficiently clear in passing, but in respect to one name a further word of explanation is needed. When Dr Spencer had traced parts of the Forest, Arkona, and Ridgeway beaches in Ontario, he named the water which made them lake Warren, in honor of General G. K. Warren, whom he regards as "the father of lacustrine geology in America." This name was first published in Science for January 27, 1888, page 49; but in this and in all his subsequent publications relating to these beaches Dr Spencer has stated his belief that they are really of marine origin. Besides calling the waters that made these beaches lake Warren, he has as frequently called them Warren water and Warren gulf. The current ideas of their size and origin have been diverse from the beginning—so much so as to make the application of the name rather uncertain. Dr Spencer has always defined lake Warren as covering the whole of the Great Lake area, and Upham and Lawson have supposed it to cover all but lake Ontario.

The whole series of beaches has been regarded as the work of one lake at as many halts in the fall of its level. This is true in a wide sense, but there were so many elements of change as the waters fell that it seems appropriate and necessary to consider the several stages as separate lakes and give a special name to each. The waters changed their shape, size, and level as they fell, and, what seems still more important, they changed the place of their outlet several times.

The need for the restricted use of the name lake Warren here proposed is a natural result of the progress of discovery. With the finding of outlets and terminal moraines intimately related to the beaches, the moraines marking the place of the ice-barrier that held the waters up, it becomes a positive necessity to recognize the new facts, and this can be done best, as it seems to the writer, by subdivision and restriction in nomenclature, as is sometimes done in the biological sciences. The whole series of lakes here described might be called the Warren lakes. This would be one way of preserving Spencer's nomenclature; but, in the writer's opinion, this use of the name would be unfortunate. A collective name ought to have some geographic significance. The name Erie-Huron which is used here serves this purpose admirably, and the name lake Warren may then be applied in a more restricted way to that one of the several separate lakes of the series which most closely corresponds to Spencer's original idea. The Forest beach marks the widest extent of the Erie-Huron glacial waters and was the last and most extensive lake of the series. It seems more appropriate therefore to call this stage lake Warren than to apply this name to any of the higher, less extensive stages.

Conclusion.

The events of the glacial recession in the region of the thumb and the Saginaw valley as revealed by the studies of the past season have been presented above in the order of their occurrence so far as possible. It seems hardly necessary, therefore, to restate them here.

The larger part of the boundaries of the Erie-Huron glacial lakes had been traced out by earlier observers before the observations here recorded were made, but it happened that the thumb of Michigan, which was critical ground for all the stages except the first or lake Maumee, remained the last to be explored. If the relations of the moraines and beaches and outlets are as given above, then outlets not certainly known before have been found for three and possibly four of the stages, and these outlets are so related to the topography of the region and to the moraines that in at least three cases there is no reasonable doubt as to the contemporary place of the ice-front. The continental ice-sheet was obviously the great dam that held all these waters up. This has been the theory of the leading geologists of America for many years; but those who have opposed the idea of the continental ice-sheet on general principles have always had some advantage in being able to assert that the exact place of the dam had not been discovered in any important case. They have demanded some evidence of the existence and exact place of the ice-dam that held up lake Iroquois, and the same for lake Agassiz, and such evidence has not been found; but in both of these cases there are great difficulties in the way of locating the ice-dam with precision. In both regions the country is rough, and moraines are hard to trace, while for lake Agassiz the country is also almost wholly inaccessible.

In Michigan neither of these difficulties was encountered. The region is generally so smooth that the moraines and outlet channels themselves constitute the main reliefs of secondary magnitude, and most of the country is well cleared. While it is true that for each stage of the waters described above something yet remains to be done before its exact boundaries can be fully known, it is nevertheless true, in the opinion of the writer, that the position of the ice-dam for all the lakes here described is either known exactly, as in the case of lake Maumee and the western end of lake Whittlesey, or is reduced to a narrow choice of alternatives. What now remains to be done to complete our knowledge of all these boundaries is a small thing compared with what has been accomplished in this direction in the past.

The writer takes pleasure in acknowledging helpful suggestions in the interpretation of some of the facts from Mr Gilbert and Mr Leverett.

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DIABASE PITCHSTONE AND MUD ENCLOSURES OF THE TRIASSIC TRAP OF NEW ENGLAND *

BY B. K. EMERSON

(Presented before the Society August 22, 1896)

CONTENTS

GRANBY TUFF.

A bed of tuff is composed of fragments of volcanic rock more or less sorted and transported by the action of water and whose fragments,

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having been cold when they were brought together, have produced no caustic effects upon one another. I know of but one important bed in the Triassic of New England which exactly fits this description. This bed I have called the Granby tuff. Its outcrop starts with the Belchertown ponds southeast of Amherst and runs parallel with, and a mile south of, the great Holyoke trap ridge, 12½ miles to the town of Holyoke.

In its eastward or shoreward portion it is enclosed in the coarse shore sandstones; in its central portion it is included in the fine sands of the deep water, and at its south end rests for miles on the upper trap sheet.

At its bend near the gap where the Connecticut river passes through the trap ridge and near the great Black Rock plug—the largest of the late volcanic cores which cut through the older traps and sandstones—it is made of blocks often one to two feet long. From here the size of the material decreases gradually to the extremities.

The sandstones beneath it are but slightly ferruginous, and the bed itself graduates upward into a very ferruginous sandstone, and is itself well bedded. It everywhere contains a certain quantity of quartz, microcline, and muscovite, minerals foreign to the trap, but forming the staple sedimentary material of the enclosing sandstones.

The volcanic material is angular and is composed of the common diabase, sometimes amygdaloidal and sometimes not. It is often much decomposed, and minute fragments can be detected with the microscope in the ferruginous sandstone above into which the tuff graduates after all trace has seemingly disappeared. Under the microscope the altered fragments of the trap rest always against the grains derived from granite without the slightest trace of any reaction between them which could be referred to heat.

The Black Rock plug is a mile square and is the only core of sufficient size to have furnished by explosion the material contained in the tuff bed, and its position is such as to make it probable that this was its source.

This is clearly the description of a true bed of tuff. The mass was projected into the air by an explosive eruption, fell into the water and was spread by it as cold material. It graduates into the feldspathic sands which were being spread over the Triassic basin before and after its advent.

White Diabase Tuff.

A smaller bed is very peculiar and deserves a brief description.

There is a low water-parting between mount Tom and Little mountain to the east, and in the bed of the brook running north, near its source, the sandstone contains a large number of small angular fragments, none more than three inches long, of a white diabase—a rock made up of a mass of plagioclase rods, with an ophitic structure like the common diabase of the region, but containing no iron and possibly a very few colorless pyroxene crystals.

In the interior the rock looks like a white silicious limestone. On the outside weathering empties the small round amygdules which are lined by perfect secondary plagioclase crystals radiating inwardly and the center is filled with calcite, in the middle of which is generally a grain of pyrite. It occurs a few feet above the Holyoke trap sheet and is the oldest tuff in the valley. It was derived, I have no doubt, from some portion of the surface of the Holyoke sheet, and is one of the abnormal forms produced by the agencies described below. I have found somewhat similar forms at Dibbles crossing and the secondary feldspars encrusting cavities are common at Greenfield.

Mud Enclosures.

GENERAL CHARACTER OF THE SURFACE MATERIAL.

See plate 3.

At Dibbles crossing, on the south line of Holyoke, at the south end of Ashley reservoir, is a most peculiar facies of the trap. The sandstones are stripped from the upper surface of the Holyoke trap sheet over a broad area. and two railroad cuts, convenient to the roadside, enable one to study the fresh rock.

For a depth of 12 or 15 feet from its upper surface the trap is filled with a pearl gray compact calcareous clay rock of just the appearance of a common clay concretion or with a thin bedded fine grained gray sandstone. It sometimes makes the impression of claystone fragments enclosed in trap, sometimes of trap fragments enclosed in claystone. The two are often intimately mixed together like two nonmiscible fluids, and the dark gray or red brown trap and the pale gray clay rock produce the effect of Castile soap. Long filaments and stringers and rows of bubbles of the clay go out very generally from the larger areas of the clay rock into the trap in a way only explicable on the assumption that a mass of the muddy clay was thrust suddenly into the liquid trap. In this same clay mass will often be found many small angular fragments of the amygdaloidal trap, showing that the trap was partly solidified and was then shattered by explosions caused by its contact with the liquid mud. At the north end of the east wall of the cutting is a sheet of the clayey sandstone, which is about twelve feet long, a foot wide at the center, and tapering to nothing at the ends. Above and below the trap is coarsely amygdaloidal or rather abounding with rounded, beaded, and variously lobed cavities, which are filled with the gray mud.* Some

* The later infiltration of calcite has changed this mud into a massive gray rock exactly like the claystones so common in the Champlain clays.

of the pores were left empty or only partly filled by the mud, and these are filled with white infiltrated calcite, making a striking contrast. In many cases it can be seen that the mud has risen from the stratified mass of the argillaceous rock to form and fill the cavities. That the bubble-like masses of mud have thus risen from this larger mass, and that they are regularly disseminated in the trap and are not simply the filling of superficial steam holes, can be clearly seen and the trap can be chipped off and layer after layer of the gray drops seen to be isolated in the trap (see plate 3, figure 1).

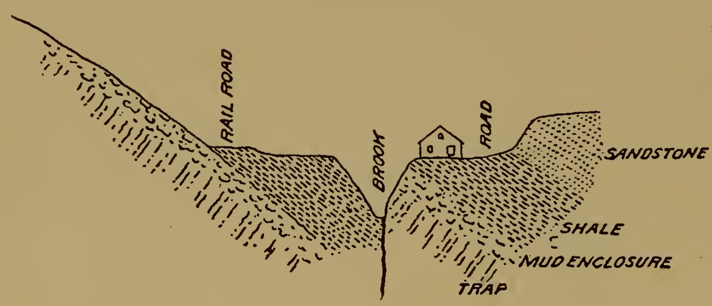

FIGURE 1.—*Section of Fault at House south of Dibbles Crossing.*

Showing shales resting on the mud-filled surface of the trap.

In one case there can be seen at the height of one's eye, at the south end of the west wall, a series of blocks filled with drops, and the mud mass from which they stream can be seen below, while now the mass containing these mud amygdules is itself shattered and its fragments cemented by more of the same mud (see plate 3, figure 2). In other places a thin gray laminated sandy shale is confusedly mingled in the trap, its layers being greatly warped and twisted. Under the microscope the mixture can be seen to be still more intimate, and while there was often a complete emulsion of the two non-mixing fluids, there is only a slight chemical action discernible. Only a microscopic layer of recrystallized carbonates appears.*

In other cases the whole wall has a coarse conglomeratic look, rounded portions of the trap as large as a fist being wrapped around by thick flakes of the thin, fissile, sandy shale as if balls of putty had been separated by being folded in thick wads of wet wrapping paper.

Above this intimate mixture a few angular fragments of scoria are enclosed for a foot or two in the thin bedded sandstones. This layer can be followed north ten miles wherever the upper surface of the trap is exposed.

THE UNDERROLLED MATERIAL.

The most striking circumstance in the whole matter, however, is the fact that at the base of this great sheet, which is from 300 to 500 feet

* If any one visits this most interesting locality, which is situated four miles from Holyoke, on the road to Westfield, the ridge running from the Dibble house south to the next house will be found cut by the railroad, showing the trap and the sandstone above. In the swale west of this small ridge is a fault, which can be seen in the brook directly behind the second house (see figure 1). West of this fault the series is repeated, and the broad surface of the trap for a mile north is filled with the foreign material.

thick for all this ten miles, the same highly scoriaceous and mud-impregnated stratum occurs inverted, presenting all the complex peculiarities described above. The pores diminish and disappear upward in the compact trap It is the same visibly crystalline trap as at the surface, and not the very black aphanitic trap usual at the base, where it has cooled in place, free from pores and enclosures. At the north base of Titan's pier, at the water's edge is the best and most accessible place to study the mud enclosures at the base, where the bed rests on coarse arkose. Specimens taken from this place cannot be distinguished from those taken from Dibbles crossing. At Titan's piazza, a hundred rods north, along the base of the same sheet, the black compact aphanitic trap rests on the same coarse sandstone, and contains only a few long steam holes.

The same state of things exists at Larrabee's quarry, at the north line of Holyoke, beside the Connecticut, at the top of the upper or posterior sheet. A black carbonaceous shale is blended with the very porous trap like a marble cake, causing its porosity, and sheets and films float in the trap of shapes which could not have been torn from the rocks below and floated up into their present place. Indeed, there are no such rocks below in any of these cases.

Just north of the quarry and across the road is a steep hill, and a fault raises the trap in this hill so that its base is exposed, and contains the same intermixture as the surface. As a very curious result of this mud-and-water impregnation the trap also contains, deep in its mass, nests of beautiful anhydrite, and the sandstone, just above, is filled with fine hematite crystals, showing it was brought quickly over the trap while the latter was still greatly heated.

ORIGIN OF THE DEPOSITS.

The following is offered as an explanation of these deposits:

The thick trap sheets have flowed out over the muddy bottom of the bay, and their heat produced strong upward convection currents and correspondingly strong indraughts from the sides, which carried muddy waters out over the surface of the trap while it was still flowing, and covered it with a quantity of calcareous mud, out of proportion to what would have been carried in the same time by the normal currents. I have seen sheets of newly solidified lava careen and slide beneath the liquid mass at Kilauea, and the sheets of mud and lava may have thus become variously mingled here, producing the results described above. The surface of the Holyoke trap sheet is filled with the fine mud just as far north as the fine Chicopee shales extend, and farther north, where the sheet flowed over coarse gravel, nothing of the kind occurred, because the coarse gravel could not be carried thus out over the thick sheet.

The appearance of the same layer at the base of the trap sheet is explained by the underrolling of the newly solidified surface of the sheet, as when a carpet is unrolled on the floor, what was on top descends along the front and comes to lie inverted beneath.

Thus the porous mud-filled surface came to form, inverted, the base of the bed, and to rest, though filled with fine mud, upon the coarse sand onto which the sheet had advanced.*

Diabase Pitchstone and Mud Enclosure.

ORIGIN OF THE PITCHSTONE.

This third process is still more peculiar and novel than the last. In a tuff bed there are no caustic effects. In the overwashed and underrolled mixture of mud and trap the caustic effects are slight, and the result appears equally in the upper and lower portions of the trap sheet.

In the present case the caustic effects are at a maximum and take on many of the aspects of metamorphism, and the work is normally confined to the lower portion of the sheet.

The flow of the submarine lava bed seems here to have been unusually rapid, and the underrolling to have been a somewhat subordinate phenomenon; still the convection currents rising from the front of the bed seem to have generally chilled it, so that a somewhat thin layer of compact, heavy, fine grained trap was solidified and underrolled to form a basal bed protecting the liquid mass above. When the sheet had advanced over the muddy bottom so far that the imprisoned vapors could not escape laterally, some slight and local disturbance broke up this

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*I have already reported very briefly upon this occurrence (Am. Jour Sci., vol. xliii, p. 147); too briefly, it would seem, as the facts given were wholly misunderstood and incorrectly quoted by Professor Dana and made to do duty in proof of the laccolitic origin of the Mount Tom trap sheet. In his Manual of Geology, on page 805, he says: "The limestone had been torn off from a layer not visible in the section."

This was the very point I was trying to disprove, both by showing that there was no bed in the older rocks of the region from which any such material could be derived, and that the shapes of the enclosures were not such as would be possible in solid rock torn off from the walls of the fissure through which the lava flowed, since it was in thin filaments and flowed in to fill all the open steam holes of the trap fragments.

On the next page, 806, he says: "But a laccolitic origin and the abrasion of the underlying sandstone are indicated by the occurrence of breccia beneath the trap, and especially by the limestone chips in the lower part of the mass of the trap, and also over its upper surface, as described by Emerson. A bed of limestone was evidently divided by the advancing tongue of melted trap, part being left below and the rest above." As Emerson observes: "The facts prove that the heavy trap flowed over the sandstone, abrading and tearing it."

This was plainly quoted from a very dim recollection of the article in question. There is no breccia beneath the trap. The inclusions cannot be called chips, and there is not the slightest evidence that the melted trap has split asunder a bed of solid limestone. I have not made in the article cited or elsewhere the observation quoted in the last sentence, since the facts all prove exactly to the opposite. I know of no facts favoring a laccolitic origin of the Holyoke trap sheet.

basal layer more or less, the heat reached the water-soaked sand below, and steam and mud frothed up into the mass of the still liquid lava in great quantity. These abnormal conditions promoted the formation of unusual varieties of trap. The absorption of water caused the formation of much basic pitchstone, while repeated smothered explosions shattered and commingled the heterogeneous products.

GENERAL CHARACTER.

For a thickness of 30 to 70 feet and for a distance of several miles in the vicinity of Greenfield the basal portion of the trap sheet is a mixture of sand, fragments of various sandstones, fragments of various kinds of diabase, some with glass base, some with hyalopilitic base, and some resembling andesites, all unlike the monotonous Triassic diabase, and abundant fragments of glass, all cemented by glass, and variously shattered and recemented, and the interstices filled by a water-deposited mixture of albite, diopside, calcite, ægirine-augite, and hematite.

The main mass of the trap sheet is normal and continuous above this confused mass, and in many places the basal portion of the sheet can be seen to be a continuous mass of trap beneath the breccia, so that the latter must have been formed in the midst of the sheet itself. The sheets are normal, cotemporaneous sheets, often showing a ropy flow structure at the surface.

GREENFIELD QUARRY EXPOSURES AND CONTACTS.

See plate 4.

For a mile north of the quarry, beneath the observation tower,* east of Greenfield, one can walk along the line of contact of the trap on the sandstone with the vertical wall of the trap rising above. Here there seems to have been no distinct basal bed, but the whole mass was cooled nearly to the crystallizing point when the sand rose at almost equal intervals, and the streams of the sand and glass breccia formed by it rise in great streaks or "schlieren," anastomose, and pass with fluidal structure around the great rounded blocks of the normal trap which make somewhat more than half the wall.

At the quarry is a more distinct basal bed of trap 7 or 8 feet thick, more or less shattered and displaced, and the sand can be seen continuous with the underlying sandstones rising in rifts in this basal bed and frothing out into a scoriaceous sandstone where it meets and blends with the breccia above. This breccia is 60 feet thick—a greenish mass of shattered glass and trap full of filaments of red sand shining with hematite scales.

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* See Deerfield sheet of Massachusetts map.

The rounded bomb-like masses of the compact and crystalline trap which are contained in this breccia graduate superficially through hyalopilitic trap into the green glass, and while compact at center are toward the surface full of radiating steam pores. They seem to have been often carried aloft by the explosions into the still liquid glass, partially melted, and made superficially plastic by reheating, so that the steam has been able to struggle to the surface from the outer portion.

Among these blocks are many long sheets and rounded masses connected by narrow necks, which could not have been blown into the air and have fallen as common bombs (see plates 5 and 6).

A little way north of the quarry one can climb up the whole face of the trap by a steep path, and 60 feet from the base can study the top of the breccia. Here are unusually large masses of sand frothed up into an amygdaloid sandstone and filled with water-deposited silicates (see plate 7, figure 3), and above this the trap is normal and crystalline and full of steam holes for a few feet, and then graduates into the common columnar trap of the upper part of the sheet.*

MERIDEN "ASH BED."

The bed at the base of the trap sheet west of Lamentation mountain, on the Berlin turnpike, two miles north of Meriden, has excited much interest locally, and some blasting has been done by the Meriden Scientific Society to open it for study. It differs from the Greenfield bed only in the much greater quantity of glass and in being only half as thick. The glass breccia rests in places upon unbaked sandstone, which is thrust up into it in sheets and tongues several feet, and there changed into an exceedingly tough quartzite by being soaked full of the glass (see plate 9, figure 1). Just south of the blasting the basal bed of compact trap can be followed for three rods to where it is covered, and the glass above sends tongues down into it, showing that they are continuous and in place. Above this basal sheet the trap blocks in the breccia are rare, small, and confined to the top of the sheet. At the blasting the basal bed has been carried up into the glass above by explosions, sometimes as broad sheets, sometimes as rounded and remelted blocks, with peripheral steam holes, and the breccia rests on the sandstone. One such rounded and bomb-like mass rests here directly on the sandstone, and the sand and glass mixture wraps around it, producing exactly the effect of a bomb fallen on yielding sand; but this sand and glass mixture wraps clear round the block and nearly or quite meet above it, and the same fluidal struct-

* In reporting my brief account of this case, also, Professor Dana has destroyed the meaning of the whole by an error. He says that the trap sheet rests on coarse sandstone breccia 12 to 16 feet thick, instead of coarse trap breccia. (Manual of Geology, 1895, foot-note on page 805).

ure appears around many of the blocks in the midst of the breccia. These blocks graduate outwardly into glass, and so have been rounded in place by remelting. Where they are large and angular they have been carried but a little way from the base where they were formed; where they are small and spherical they are far-carried and much resorbed in the glass mass.

The locality is peculiar for the great quantity of basic pitchstone, which, while greatly mixed with sand and trap fragments for a few feet up, is an almost pure shattered green to liver brown pitchstone (red brown by transmitted light) for 20 feet above. It has the fine conchoidal fracture and the greasy luster of a pitchstone. It is sparingly spherulitic and has at times a fine perlitic structure, and the minute egg-shaped or spherical spherulites slip out of their places with polished surfaces. The lens shows sparingly minute feldspar-rods and larger pyroxenes and olivines. The structure of the whole is disguised by the intermixture of calcite and ankerite. Large areas of pure pitchstone can be found up the south path, and on the bluff over the blasting is a great block of a fine brown hyalopilitic diabase.

This breccia bed is said by Messrs Davis and Whipple,* who studied the trap sheets carefully with special reference to the question of their intrusive or extrusive origin, to extend but a little distance north and to be continued a mile and a half southeast.

ERUPTION OF GLASS BRECCIA THROUGH TRAP SHEET.

Half a mile north of the last outcrop, is an interesting locality, described by Davis and Whipple as—

"a local trap conglomerate in the same horizon with the anterior sheet. Vesicular and water-worn pebbles are here interbedded with sand, as if this point were not far distant from a wave-beaten margin of the anterior lava sheet." †

The place is on the same trap ridge and may be found by going north from the last locality along the Berlin turnpike to the point where a road comes in from the southwest. Opposite this road a wood road runs east to the ridge, and going a few rods north one comes to a fine point of view of the lake to the west, where beacon fires have been built. Directly beneath in the bluff is a rock shelter, and the southern wall of this is the south wall of the throat to be described.

The explosive force of the steam at the base of the trap sheet has formed the same brecciated agglomerate as before, but has here forced its

* The intrusive and extrusive trap sheets of the Connecticut valley. Bull. Mus. Comp. Zool., Geol. Series, vol. ii, p. 118.

† Loc. cit., p. 108.

way through the whole thickness of the trap sheet in a throat three rods wide and flowed out on the surface as a submarine mud volcano. As shown below in figure 2, the walls of the throat are clearly exposed. At the lowest point visible the trap is rudely columnar and compact. It graduates upward into a scoriaceous trap, and this is covered by a layer 5 to 6 feet thick, made up of angular blocks of the same scoriaceous trap, which are slightly moved on each other. This is plainly the undisturbed surface of a normal lava flow.

The mass that rises in the throat and spreads over the lava sheet has all the peculiarities of the breccia farther south. It contains the rounded bomb-like trap blocks, isolated blocks of indurated white sandstone containing blebs of pitchstone and rounded by abrasion; blocks of scoriaceous red sandstone, also containing pitchstone and fragments of the jet-black; fine-grained basal trap, often full of the long steam tubes which are

FIGURE 2.—*Generalized Section of Overflow of Glass Breccia through Trap north of Meriden.*

usually found at the bottom of the trap, together with various other trap varieties. The whole is cemented by glass, and the secondary albite-calcite-diopside mixture, as in the other cases. It rises over the lips of the throat and flows southward. It graduates up into a tuffaceous sandstone, bedded by water, and full of ferruginous concretions. The breccia can be followed north about 30 rods. I traced it south about 40 rods. It is doubtless continuous with the two thin layers of tuff in the sandstone above the trap east of the ash bed described in the last section, which were mentioned by Davis and Whittle.*

"An interesting point is the occurrence of two thin layers of tufa in the sandstone just above the trap, each about an inch in thickness and about a foot apart. These layers appear in a hand specimen of a rusty brown color, composed of water-worn fragments of trap mixed with clastic quartz, and have a much weathered ap-

* Loc. cit., p. 120.

pearance. Under the microscope their tuffaceous character is well shown; vesicular porphyritic trap grains abound, and others of non-polarizing character are derived from yellowish glass, now wholly or partly devitrified."

Petrographical Descriptions.

SURFACE OF BEDS AT DIBBLES CROSSING AND LARABEE'S QUARRY.

At Dibbles crossing the mudstone which has passed into the trap is mottled with brighter spots where the calcite is concentrated in minute concretions, forming a partial oolitic texture.

The trap shows the two generations of plagioclase in a marked degree in a basis which seems to be devitrified glass, but made black by fine granular black ore. The iron being altogether in this form, augite is wanting.

Sometimes when the mud has shrunk away from the trap a drusy crust of obtuse scalenohedra of calcite appears under the microscope; upon this a coating of siderite or ankerite rhombohedra, now rusty in cleavage planes, and above this a crust of quartz prisms. The trap contains pores filled with mud with secondary calcite. Other round, pale green spheres of green glass polarizing faintly in a small portion of the surface are of problematic origin.

At Larabee's quarry the black mud is intimately mixed with the trap, which shows large and small feldspars in a beautifully tufted hyalopilitic basis or in a basis of devitrified glass black from magnetite grains. The mud produces a minimum effect upon the trap; only a black, dense surface of the cavities is produced. The mud often lines the whole of a cavity as a thin film (apparently by the expansion of the steam pressing it against the walls). The center is filled by coarse calcite.

BASE OF HOLYOKE BED.

At the foot of Titan's pier the same drusy crust as above occurs. There is also a microscopic layer of a curdled impure glass at the surface of the trap fragments.

Sections cut from the base of the Holyoke bed at the peak west of Norwottock show a greater amount of change. A layer of bright green glass, with sharp, small feldspar rods and black magnetite dust, encloses and penetrates the red sand. This glass contains also distinct crystals of calcite. A narrow band of this glass adjacent to the sand is slightly devitrified in fibers parallel to the sand surface. Next outside this a band of magnetite grains separates it from a band, showing an indiscriminate mixture of the green glass in small, irregular patches, with a transparent granular calcite. With polarized light the glass is seen to run through the granular calcite like micropoikilitic quartz in a feldspar. It produces entirely the impression that the calcite has crystallized in the midst of the glass as the feldspar has.

It is further striking that the red sand is quite full of long "lathes," which have the shape and appearance of the plagioclase rods of the glass, but which now show the aggregate polarization and consist, probably, of calcite pseudomorph after plagioclase.

GREENFIELD BED.

Glass breccia.—Under the microscope a fragment of the greenish tuff-like mass, taken 20 feet from the base of the Greenfield bed, was composed as follows:

The first thing that attracted attention was the fine red sand, each grain being covered with iron rust. Where this was in thick masses it was still red in the interior, but on the exterior was black from the recrystallization of the iron rust by the caustic effect of the melted lava, in which it had been disseminated in threads and sheets. In the interstices between these dark sand portions many minute angular grains of diabase, like that found in the basal bed, were scattered. These had been broken up by an early explosion and carried up from the base with the sand. The whole had been cemented by an olive green glass, containing a few crystals of plagioclase and scattered spherulites, penetrating among the sand grains and to the very center of sand areas, which would otherwise have been called sandstone fragments. The whole thus formed has been again shattered, and is now cemented by a hot-water deposit of albite-calcite-diopside and ægerine-augite. Beautiful large hexagonal plates of hematite bristle over the trails of sand grains, and in all the other constituents except the basal trap fragments. Sometimes cavities of later formation are filled by radiating chalcedonic growths, with centers of calcite and ankerite and copper pyrite.

The water-deposited plagioclase (plate 7, figure 2) has the appearance and the optical character of the small but perfect albites (plate 7, figure 1) which line the steam holes in many places in this bed and often rest upon the earlier delessite. These I have proved by optical and specific gravity tests to be albite.* It has also a curious resemblance to the albite of the "albitic" schists and amphibolites, and the whole mixture has some resemblance to a crystalline schist.

The ægyrite-like mineral (plate 7, figure 2) is in shapeless grains and shows a strong prismatic cleavage. It is intergrown with the feldspar, calcite and diopside in such a way as to show they were all deposited together.

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* Mineral Lexicon: Subject, Albite. Bull. No. 126, U. S. Geological Survey.

The absorption in this mineral is very strong: 𝔞 = blue, 𝔟 = yellowish green, 𝔠 = brownish yellow. A single twin with an extinction of 38 degrees on either side of the suture was found, and the maximum of the blue absorption was also at 38 degrees on either side of the suture, and this blue absorption represented the greatest elasticity. The mineral thus has the positive sign and the strong absorption of ægyrite and the optical figure in the position of augite. The mineral is thus nearer ægyrite than the ægerine-augite of Rosenbusch, in that the absorption parallel to 𝔞 is clear blue and not grass green. Large patches of the mineral are changed to a yellow green serpentinous mineral, which under crossed nicols is almost black, but with scattered points of light.

The diopside is in stout small crystals or in long stout prisms, sometimes broken. They are enveloped by the ægerine-augite without common orientation.

Amygdaloidal sandstone.—One of the columns of sand rising from the sandstone and penetrating the basal bed at the Greenfield quarry expands nine feet from the base where it passes above the basal bed into the glass breccia, and its central portion presents a scoriaceous appearance. It is a red sandstone filled with more or less rounded spots of a white silicate which I have no doubt, from my examination of other similar cases, is mainly a granular plagioclase. The same thing is developed much more extensively on the path going up over the cliff north of the quarry. Here for several feet in thickness the rock is a red sandstone closely filled with small cavities. The whole makes the impression of a rather coarse red amygdaloid with white amygdules.

A still more attractive form of the same rock is found in the cut of the electric road at the Deerfield river, a mile south of Cheapside (see plate 7, figure 3). Here a light red sand rock is filled with the fresh white amygdules, producing a very attractive rock. Under the microscope the sandstone between the white fillings has a beautiful fluidal structure, thus heightening the resemblance to an amygdaloid. The cavities are superficially blackened by the recrystallization of the iron oxide. The white filling is mainly a fresh matted network of plagioclase blades, which shows distinct triclinic striation, rather more frequently than is usual in this water-deposited feldspar. They are ragged edged from interference due to rapid crystallization. In the center of the cavities is another mineral into which the feldspars penetrate with a micropegmatitic structure or which runs out among them. It polarizes with bright yellows, and I suspect it to be datolite, as a mineral with the high glassy luster of datolite can be seen with the lens in the centers of some cavities. It may be diopside, but shows no cleavage, and it has a rough surface like olivine, which agrees with the high refractive index of datolite. Another peculiarity is that the cavities seem to have been filled with the mixture described above, and then the sand has shrunk away from the filling for a considerable distance along one or more sides, leaving a film of the black sand grains attached, and then a more limpid feldspar has grown in the narrow cavities thus formed.

Contact material.—A slide cut within the porous outer portion of the trap from the contact of the bomb-like masses of trap with the glass breccia, showed only a very feldspathic and vesicular diabase.

Specimens cut from the fused border between the two showed a rock with the aspect of an augite-andesite (see plate 7, figure 5). The well shaped feldspars of two generations and the equally well shaped olivines were enclosed in an opaque red brown base, which in thinnest places revealed its hyalopilitic structure. Its outer surface had at times a rounded and lobed fused surface, and just under the surface a single row of rounded and lobed steam holes filled with silica, all indicating a superficial remelting.

Lithophysæ.—In one large specimen from near the base of the bed north of the quarry at Greenfield the breccia was full of well formed lithophysæ a half inch to an inch and a half in diameter. The cavities were half filled with curdled masses of a lighter rock. Indeed the collapsed steam holes in the pure glass where the wrinkled walls show a fluidal structure suggest lithophysæ (see plate 8, figures 4 and 5).

MERIDEN "ASH BED."

Basal bed.—The diabase at the bottom of the normal and unmoved basal bed south of the blasting is a very fresh, fine grained, compact trap, in which rarely a fine microscopic steam hole occurs. It has a few small cavities filled with delessite. It is very feldspathic and the two generations of feldspar graduate into each other, are much feathered out at the ends, and make a regular network, in the meshes of which lie the augite grains. The peculiarity of this trap consists in the fact (which is true of the base of the overflows in many cases) that the interstices between the feldspar rods are very often filled with beautiful arborescent growths of magnetite, consisting of long lines of octahedra branching at right angles to the central stem. This seems due to gravity, or possibly to incipient magmatic differentiation.

Hyalopilitic diabase.—(See plate 7, figure 5.) In a specimen taken from the north edge of the continuous portion of the basal mass, two feet above the base, where it graduates into the glass breccia, a light yellowish gray compact part seemed to be an indurated sandstone, but proved to be a margaritic diabase. The whole ground surrounding the porphyritic feldspars has solidified as a matted mass of curved and beaded feldspar microlites, which are brought out with bluish white light by crossed nicols. They are red brown by transmitted light from the ferrite grains of the former brown glass, crowded between the rods, and silvery white by reflected light.

Exquisite tufts and sheafs of feathery, beaded microlites overlap each other to form an opaque ground, except in thin slides. They reproduce the structures figured by E. S. Dana from Kilauea.* Beautiful specimens for slides can be obtained from the great mass of liver brown aphanitic trap on the bluff just above the blasting.

Diabase pitchstone.—Mr George W. Hawes was apparently the first to mention the occurrence of glass and the last described variety of diabase.†

In its purest form, as found in a great block at the top of the bluff, it is a dark liver brown pitchstone, dull green, or mottled brown and green, by reflected and red brown by transmitted light. In the cliff wall below it is often an apple green glass with the same dichroism. It has resinous pitchstone luster, and so differs from most tachylites. The microscope shows a very minute, regular network of cracks, often developing into a perlitic structure around crystals and spherulites, which explains this luster. The deep brown glass streaked with very deep brown is wholly amorphous and hardly to be distinguished from the Kilauea glass in common light, and, like it, it is not affected by acid. The phenocrysts are of similar size and distribution, but with polarized light the feldspar rods are always, and the large colorless pyroxenes sometimes, changed to granular calcite, easily removed by acid; the olivines to fibrous serpentine (see plate 8, figures 4 and 5).

The fresh glass is full of small grains (cumulites), white by reflected, red brown by transmitted, light, which are made of aggregates of minute grains (globulites). Even where the glass seems compact it often separates into small sheets and portions showing minute curdled surfaces, and under the microscope the same wrinkled surfaces can be seen, where small cavities have collapsed or where the surface of fragments have flowed or have been drawn out in threads. In one case a large fresh pyroxene resting alone in the fresh brown glass has been bent 35 degrees without fracture during the torsion of the glass fragment (see plate 8, figure 5).

The glass has been shattered into angular fragments by sudden explosions, while still able to flow under slow pressure. Each of the fragments is then bordered by a layer of even thickness of paler brown and equally non-polarizing glass, an effect of the heated waters on the iron content (see plate 8, figures 4 and 5).

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* Am. Jour. Sci., vol. xlvii, p. 441.
† Proc. U. S. Nat. Museum, vol. iv, p. 129.

In another specimen of apple green glass from near the top of the stratum each fragment is bordered by a band of greenish yellow glass (see plate 7, figure 4), crowded full of round spherulitic spots, which are red brown at center and graduate into aureoles of pale yellow, which pass quickly into the greenish yellow border. They polarize brightly, show black cross, but are not fibrous. They are spherulites produced by tension, not by fibrous growth. The larger fibrous spherulites in the glass (see figure 3 and plate 8, figure 1) are usually perfect circles or ovals, but they are sometimes distorted by flow or pressure. They are often bordered by several concentric bands of lighter and darker brownish green glass, each band having a concentric radiate structure. The central part is colorless and beautifully radiate-fibrous, showing perfect black cross. The fibers are optically positive and polarize like a plagioclase. They are not affected by boiling acid or alkali. Sometimes the centers are filled by a greenish granular mass, which scarcely polarizes, showing only scattered light points. The spherulites are often broken and found in parts in the breccia, and the layers separated and crushed, so that the glass seems full of fragments of eggshells. Drops of red glass drawn out in threads are devitrified in the same way (see plate 8, figure 2).

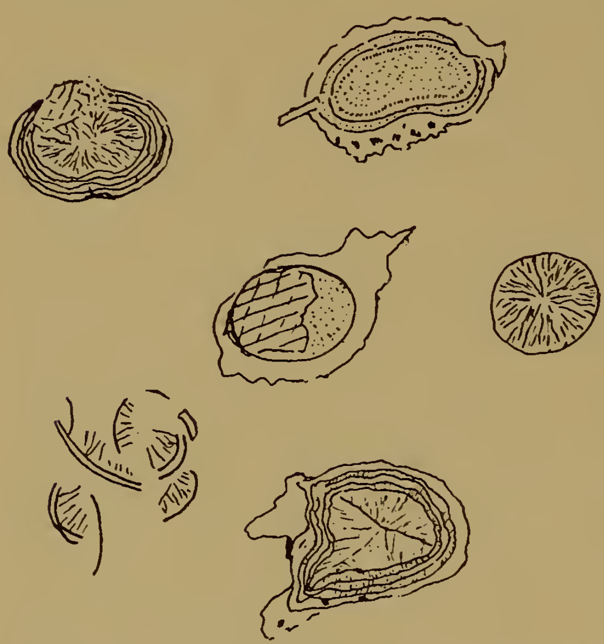


FIGURE 3. –*Forms of Spherulites* (magnified 40 times).

A similar fibrous devitrification sometimes affects all the fragments of a slide, each one being now a pale yellow devitrified glass of a finely tufted or fibrous structure radiating from many centers. The fibers have the same optical properties as those of the spherulites (see plate 8, figure 3). The enclosing glass is more granularly devitrified, polarizing in dots.

Treated with acid and fuchsin, the centers of some spherulites and the halo surrounding them were dissolved. The primary phenocrysts were not affected. The enclosing glass was slightly affected by fuchsin and bluish; the fibrous glass was much dissolved and stained strongly.

The feldspar rods are generally well formed crystals, and large groups of sharply defined colorless pyroxenes sometimes occur together with scattered olivines of equally perfect form. They often enclose blebs and lobes and are themselves surrounded by a layer of a glass much deeper brown than the surrounding glass.

The glass sometimes undergoes a peculiar calcification, which seems to me rather a metamorphic change produced by the heated waters than a later decomposition by cold atmospheric waters. A fragment of glass will be red brown at the center, pale brown farther out, and perhaps colorless at its border (see plate 9, figure 2). Its angular boundaries will be sharply defined and the phenocrysts equably disseminated through the whole, and with common light the whole seems unchanged glass.

It will, however, polarize in whole or part in broad patches of bright and softly blended colors and show everywhere the uniaxial figure of calcite. Acid removes it readily and leaves only a powdery remnant. The outer colorless part is generally devitrified in plumose patches or in series of minute fibrous globes in the greenish fibrous devitrified glass. The calcite disappears rapidly with acid, leaving an opaque white granular residue, while the white glass becomes opaque white in lines and streaks showing a concealed fluidal structure.

It is noteworthy that among all the reactions carried out here so little quartz is set free. Under the influence of the heated and carbonated water the glass, rich in calcium and other alkalies and poor in silica, tends to split into calcite and acid feldspars. This explains the formation of spherulites and the fibrous devitrification of the glass, with the abundant development of calcite.

Glass and sand.—The above glasses came from the top of the breccia bed, where the water or water vapor penetrated without carrying any of the impurities derived from the sandstone. Below this, in specimens taken from the lower portion of the bed, the glass is mixed in every conceivable way with the sand. Large patches of the glass are exactly like the deep red brown glass mentioned above, but when examined with polarized light are seen to be made up of broad patches of calcite.

These glasses, where they come in contact with sand (plate 9, figure 2), show often thin bands of alteration of the central red glass, first, outside the red glass itself, a pale yellow non-polarizing layer, then a pale yellow or colorless layer, polarizing in white lines and dots, and, lastly, a colorless, narrow, highly refracting band, which stands out like a cord between the glass and the sand. At times this band is broken and the parts moved, and the white or pale yellow glass is continuous outward as a cement uniting the sand grains together. This narrow cord-like band then often encircles each of the grains, leaving apparently empty interspaces, as one sometimes sees the pebbles of a conglomerate cemented by calcite or silica (see plate 9, figure 1). Treated with boiling HCl and concentrated boiling HKO, the green central part of the glass where it was thickest between the grains seemed to be in part removed, and threads and bands of the glass passed across to unite with the cord of glass which surrounded the adjacent sand grains and which was not in the least affected. The brown non-polarizing glass was also not much affected by this treatment. Strong hydrofluoric acid quickly dissolved all that remained of polarizing minerals, while the fresh brown glass was dissolved more slowly. This cord is thus not calcite or chalcedony, and it seems to be a peculiar form of the glass, perhaps more acid than the rest, caused by its sudden cooling in contact with the foreign grains. This capillary soaking of the glass out into the sand, thus forming what seems to be a quartzite with abundant silicious cement, is very abundant in the lower part of the bed. The sand thus cemented by the glass contains sometimes sharp fragments and tears of a glass of earlier formation. It is at times very muscovitic and has a beautiful flow structure, showing that it was a mobile mud when mixed with the glass fragments.

MERIDEN MUD VOLCANO.

The mass filling the throat of the opening in the trap ridge consists of rounded bomb-like blocks of trap and abraded blocks of various forms of sandstone, often containing glass, with the interstices filled with finer fragments of the same and the whole cemented by glass often devitrified or calcified and by the aqueous albite-diopside-calcite mixture. The hematite and the ægerine-augite of Greenfield are wanting and the glass is less abundant than at the southern bed. The glass often sinks to a capillary film between the grains. Sometimes six or seven varieties of diabase can be seen in a single slide (see plate 9, figure 5).

Primary grains of plagioclase derived from the sands and having the banding characteristic of granitic plagioclase and the large size, angularity and rust covering of the sand grains are extended by a broad layer of secondary plagioclase which projects out into the glass on all sides with irregular tongues, which are untwinned, but which extinguish with the nucleus. In some cases the central grain could be seen to have a positive optical figure in position like that of albite, together with the small angle of extinction of that mineral.

Among the interesting inclusions in the glass are—

1. Minute perfectly rounded grains of the finer sandstone found below the trap.

2. Rounded tears of the red-brown glass.

3. Fragments of the basal trap, which are densely black from the abundance of ore and which are melted on the surface and surrounded by a smooth rim of a lighter brown blebby glass, from which threads go out into the enclosing mass (see plate 9, figure 3).

4. A variety of the volcanic rock characterized by the large number of minute perfectly round steam holes which are commonly in pairs or in two conjoined spheres forming a "figure of eight" section. This indicates that the rock was solidified near the moist mud, from which bubbles escaped rapidly, and that it congealed rapidly and without motion. The base is a dark gray, slightly brownish glass filled with a fine brown dust concentrated around cavities and crystals. It contains rarely an angular grain from the sandstone, showing that it was consolidated during the upward passage of the muddy water and then shattered. The glass swarms with feldspar microlites. There are also a few small feldspar rods and a single colorless pyroxene crystal (see plate 9, figure 4).

5. Another fragment of a slightly different glass has pores which are long, multilobate, and parallel, thus showing sluggish motion. These two are almost the only cases of steam holes in the glass breccia.

Chemical Discussion.

In his article on the lavas of the Sandwich islands and other volcanic islands of the Pacific, Cohen states * that all the basic glass found was anhydrous, and, in general, a basaltic pitchstone has not been described.

I have studied slides of many tachylites, and only that of Ostheim in Hessen, with its green superficial color and liver brown interior color, resembles these glasses. I have not seen any analysis of this rock giving water determination. It is deeper brown than most of the glass here studied, and contains large, round-oval spherulites, with still deeper color, with radiate structure, and druzy surface. The other basaltic obsidians quoted by Zirkel do not contain more than 2.75 per cent of water.

The following analysis of basic pitchstone from the Meriden "ash bed," by Mr H. N. Stokes, of the United States Geological Survey, was made on the pure liver brown glass from the large mass at the top of the bed on the south path. It has specific gravity of 2.87 and melts easily to a black magnetic and frothy glass (see plate 8, figures 4 and 5):

Basic Pitchstone from "Ash Bed" northeast of Meriden.

SiO_2	46.86
TiO_2	1.13
CO_2	2.19
P_2O_5	.15
F	trace.
Al_2O_3	13.96
Fe_2O_3	5.23

* Neues Johrbuch für Mineralogie, vol. lviii, p. 57.

FeO		4.67
NmO		trace.
BaO		.03
SrO		trace.
CaO		9.42
MgO		7.69
K_2O		2.02
Na_2O		1.85
Li_2O		trace.
H_2O	at 110°	1.29
	above 110°	3.43
		99.92

Origin of the Glasses and Minerals.

It remains to consider the cause of so extensive a development of glass in the midst of the trap as a result of the introduction of water and sand in so great a quantity.

It would seem probable that the introduction of so much quartz may have permitted some solution, and thus that the glass being more acid was more apt for the vitreous form. The percentage of silica is, however, somewhat less than in the average of the diabase, and a study of a great number of slides failed to show any trace of quartz or tridymite, except as a late vein filled with coarse calcite and analcite. Slides boiled with concentrated HKO failed to show any change.

It is more probable that water has been absorbed in such quantity as to have contributed to the observed result. While obsidians are water-free, pearlstones average .03 per cent of water, and pitchstones .07 per cent, while the corresponding porphyries average only .01½ per cent.

It is remarkable, considering the quantity of water which must have been carried into the mass with the mud, that there is almost no trace of amygdaloidal development. Only one fragment of a trap enclosed with others in a breccia contained small steam holes as described above.

The collapsed cavities with wrinkled interiors and the absence of the common steam holes are explained by the absorption of the water by the glass, and this absorption explains the unusually large development of basic glass in connection with this exceptional occurrence. Above the compact and columnar trap which rests on this hydrated glass is the usual coarsely amygdaloidal surface layer of the trap, whose moisture seems to have no connection with this development at the base of the bed, and yet it is in this surface amygdaloid in the Deerfield bed that I found perfect secondary albite crystals resting on delessite in the amygdules.

The great abundance of calcite and its intimate admixture with the other constituents is remarkable. I have elsewhere given reasons for thinking it in great part formed during the consolidation and cooling of the glass. It is consonant with this that the feldspars formed during this cooling, especially those in the spherulites, are quite acid, while Hawes found very basic feldspars an abundant constituent of normal trap.

Boiled with strong hydrochloric acid and treated with fuchsin, there is no trace of decomposition and the optical characters indicate a very acid feldspar. The CO_2 brought into the mass by the waters from the coal-bearing sandstones below may have taken possession of a large portion of the Ca, leaving the Na to go into the newly made feldspar.

The similarity of these aqueous feldspars to those in a metamorphic schist is remarkable, and it is interesting to find diopside and the blue ægerine-augite and hematite formed with it, thus making a very peculiar crystalline schist in a very peculiar position.

It is again remarkable that delessite and its serpentinous decomposition product is rare in these glasses and the associated traps. This militates against the idea that the penetration of the ground waters into the liquid trap is the cause of its chloritization.

Résumé.

The normal tuff formed of water-borne trap fragments, cemented when cold by rust, is contrasted with rocks made in the upper or lower parts of submarine lava flows by the intimate commingling of mud with the liquid lava. This takes place by two quite distinct processes.

The fine mud is carried out over the surface of the advancing sheet and sinks and becomes variously blended with the liquid lava for a depth of 10 or 20 feet. This takes place over an area of the surface which, measured about parallel to the advancing front of the sheet, exceeds 10 miles, and measured at right angles to the front, about half a mile.

Because so large an amount of mud was carried out over the sheet while it remained so liquid that the two could blend, it is assumed that convection currents set up in the water by the heat of the trap, acting as indraughts from the adjoining muddy bottom to the lava sheet, spread the mud more rapidly than ordinary currents would have done.

As exactly the same mud impregnation occurs at the base of the sheet, even where the sheet rests on coarse gravel (arkose), and as it is confined to the same limits, it is assumed that the superficial blended layer was carried forward and down the front of the moving sheet, and so underrolled upon the gravels on which the sheet had advanced.

As the mud is mingled with the surface layer of the trap when cooled nearly to its solidifying point, only slight chemical changes occur. This, and the fact that the formation occurs at the top and bottom of the bed, distinguishes this process from the other.

In the second process the lava bed flowed over the muddy bottom quite rapidly, and the heated mud and water have frothed up into the still liquid mass, causing an intimate blending of sand and lava for a thickness above the base of the bed of from 30 to 75 feet and for a distance, parallel to the advancing front of the sheet, of several miles.

The sudden introduction of so large a volume of water has caused the mass to cool as a spherulitic glass, with a minute crackling, which gives it a pitchy luster and a large content of water (4.72 per cent.), thus forming a basic pitchstone which does not seem to have been described before.

As a further direct influence of the water on the lava, many abnormal forms of trap were made locally. The liquid mud rose in the liquid lava with many explosions, shattering the abnormal mixtures already solidified, and blending them in still more complex mixtures while the newly solidified glass was still slightly plastic.

The whole is cemented by the remnant of the glass, or an aqueo-igneous stage follows the igneo-aqueous, and a more distinctly hot-water product, consisting of albite, diopside, hematite, and calcite, and ægerine-augite forms the cement. This glass breccia is proved to be an integral portion of the trap sheet by the fact that there is a heavy basal bed of crystalline trap resting upon the sandstone, and the breccia graduates downward into this bed, as it does also upward into the overlying crystalline trap which forms the major portion of the overflow. Sometimes this basal bed is shattered and its parts carried up into the glass and rounded and filled with superficial steam holes by remelting.

At one point the trap sheet was broken through and the mixture of glass, trap fragments, and sand welled up through the orifice as a mud volcano and graduates upward into the ferruginous sandstone.

Explanation of Plates.

Plate 3.—*Inclusion of Mud in upper Surface of Trap Sheet.*

Figure 1.—A block of trap from the contact of a sheet of sandstone 12 feet long and a foot wide, which was included in the trap a few feet below and parallel with the surface. The lower surface of the specimen was in contact with the sandstone. The whitest spots are steam holes, filled by secondary calcite. The trap is full of drops and lobate masses of the gray mud. From the north end of the east wall of the cut. Dibbles crossing, Holyoke. About two-thirds natural size. From photograph. See page 61.

Figure 2.—Polished surfaces of pieces from the south end of the cut to show the intimate mixture of the shattered trap and the light gray mud. The mud fills many of the steam holes in whole or part. Natural size. From photograph. See middle of page 62.

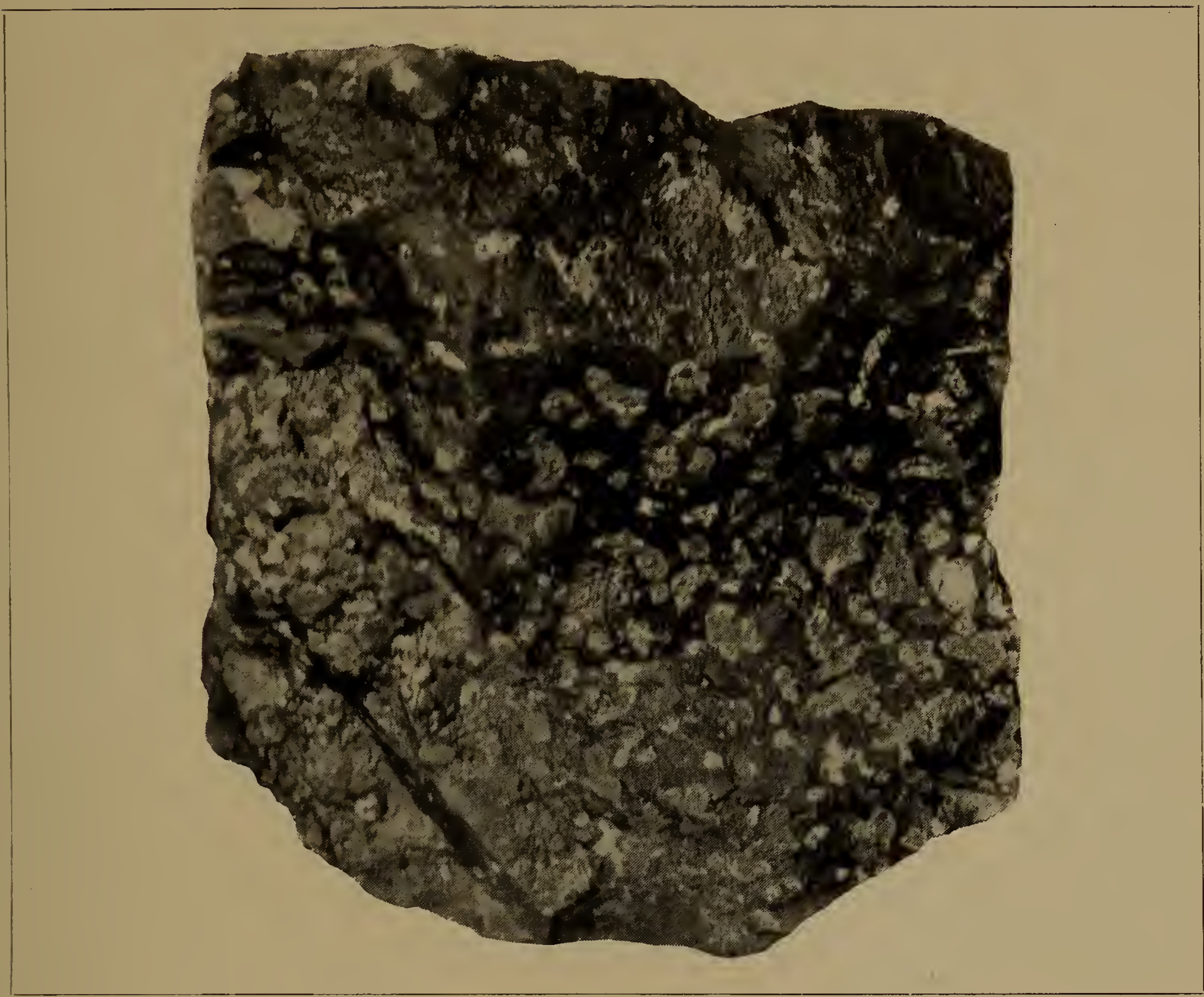


FIGURE 1.—TRAP INCLUDING DROPS OF MUD

FIGURE 2.—POLISHED PIECES SHOWING MIXTURE OF TRAP AND MUD

INCLUSION OF MUD IN UPPER SURFACE OF TRAP SHEET

TRAP RIDGE EAST OF GREENFIELD

Plate 4.—*Trap Ridge east of Greenfield.*

A winter view, looking east, of the trap ridge east of Greenfield. The sandstones project from the snow. The vertical walls above the snow consist of the sand and glass breccia, which extends up to the base of the higher bluffs above. Beneath the depression in the skyline north (to the left) of the tower is the quarry. The path to the summit goes up the next depression to the north, and where the snow lies deepest in this depression, nearly at the summit, is the place mentioned on page 66, where the trap is so full of mud that it becomes a scoriaceous sandstone. Plates 5 and 6 are taken from the south face of the great boulder that lies in the foreground. The trap sheet dips east from the observer, and the scoriaceous upper surface of the sheet is not seen.

Plate 5.—*Detail of Trap Ridge east of Greenfield.*

Photograph of the south face of the large boulder seen as a black surface in plate 4. The rounded and angular blocks are trap, and they are enclosed in the sand and glass mixture, which often shows fluidal structure.

Commencing to the right of the watch-chain, which is to be seen in the lower left-hand corner of the picture, and continuing upward for twice the length of the chain is a series of four rounded blocks connected by narrow necks and sending out narrow, angular lobes—forms which can not have resulted from explosions throwing masses of lava into the air. The effect of the pile of great round blocks with comparatively small amount of interstitial matter can only partly be given by the photograph.

DETAIL OF TRAP RIDGE EAST OF GREENFIELD

DETAIL OF TRAP RIDGE EAST OF GREENFIELD

Plate 6.—*Detail of Trap Ridge east of Greenfield.*

Enlargement of the part of plate 5 which lies to the right of the watch in the photograph. A band of the sand and glass mixture extends across from the upper right corner and separates a large, rounded block above from a double block below, whose parts are joined by a narrow neck near the center, while the part to the right sends down a long, curved lobe into the breccia below. This shows one of the forms which can not have been "bombs" in the ordinary sense.

Plate 7.—*Thin Sections of Material from Greenfield and Meriden "Ash Bed."*

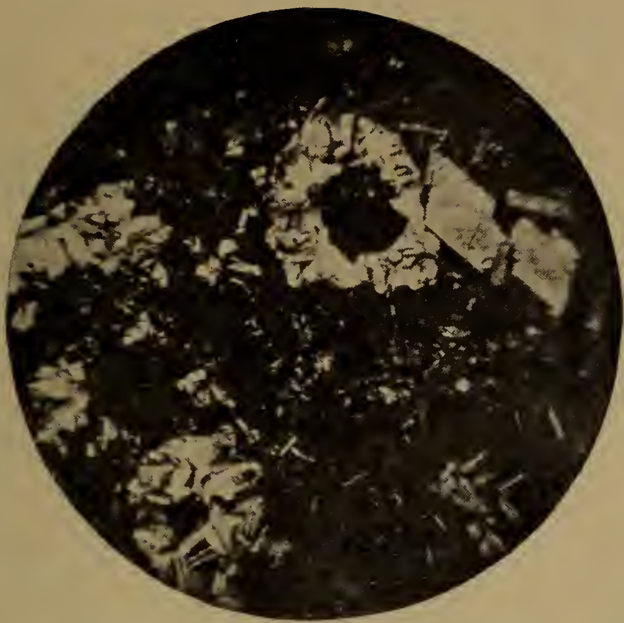
Figure 1.—Red hematitic trap with secondary albite in perfect twinned crystals lining the interior of steam holes. Two large half-filled cavities and three smaller ones, wholly filled, appear. The large porphyritic plagioclase to the right is mottled from decomposition. Greenfield near Cheapside village, at the electric railroad cut. See page 70. Magnified 20 times; crossed nicols.

Figure 2.—The interstitial aqueous deposit of plagioclase (probably albite), diopside, and ægerine-augite. The plagioclase has a dusty altered center caused by an early change to calcite and a limpid exterior of later formation, which resembles the secondary plagioclase of figure 1. The diopside is marked by strong boundaries and distant cleavage. The ægerine-augite is in dark patches. The darker bordering portions are altered to serpentine with development of cleavage. At the border, patches of the black sand appear. At the top is an isolated spherulite. Greenfield quarry, 20 feet above base of bed. See page 70. Magnified 35 times; crossed nicols.

Figure 3.—Scoriaceous sandstone. The dark parts are the rusty sandstone, red in the interior of the bands, and blackened by heat exteriorly. They show mud flow. The light parts are irregular, limpid, plagioclase grains. The mud has shrunk away at the top from a first growth of this kind, leaving a thin film of black grains, and in the narrow space a more limpid, plagioclase growth occurs. In the center of the older growth is a highly refringent mineral (datolite ?) showing a micropegmatitic structure with the plagioclase. See page 71. Greenfield, Cheapside cut. Magnified 20 times.

Figure 4.—Greenish brown glass with yellow borders, which are devitrified in series of small spherulites with darker centers. The glass has been shattered while the fragments were slightly plastic. The fragments are in place in the slide and the cavities are partly filled by a secondary water-deposited albite growth. See page 74. From Meriden "ash bed," near top on South path. Magnified 35 times.

Figure 5.—Hyalopilitic diabase from the Meriden "ash bed." Base formed of tufted, feathery, and fasciculate groups of beaded threads. Large olivine at right, large augite full of glass enclosures on left. Contact of basal bed on glass breccia. See page 72. Magnified 35 times.



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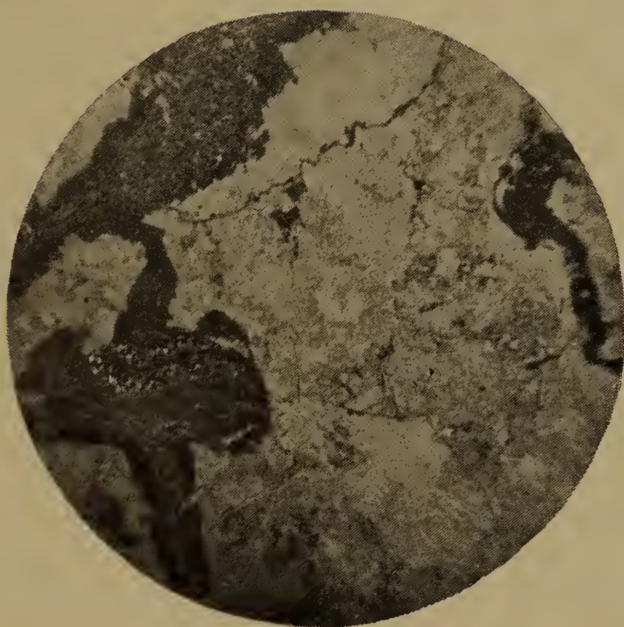

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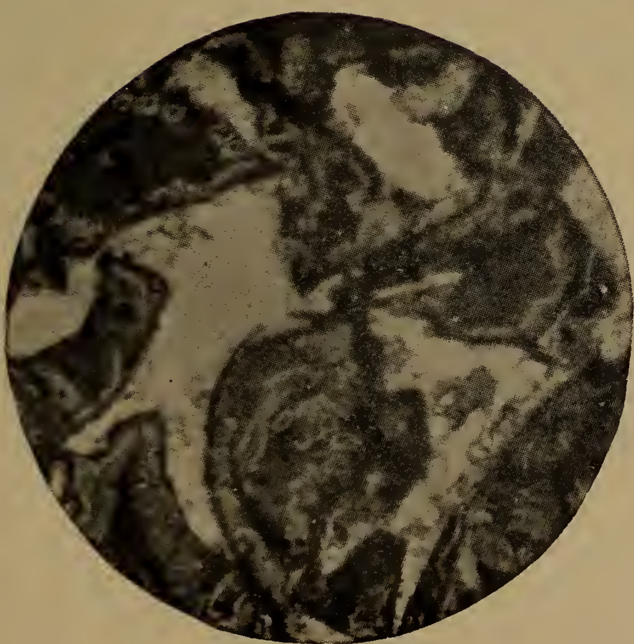

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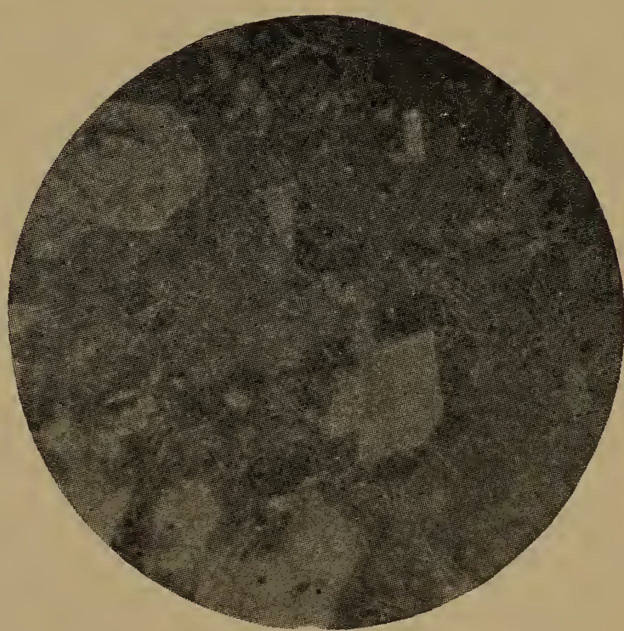

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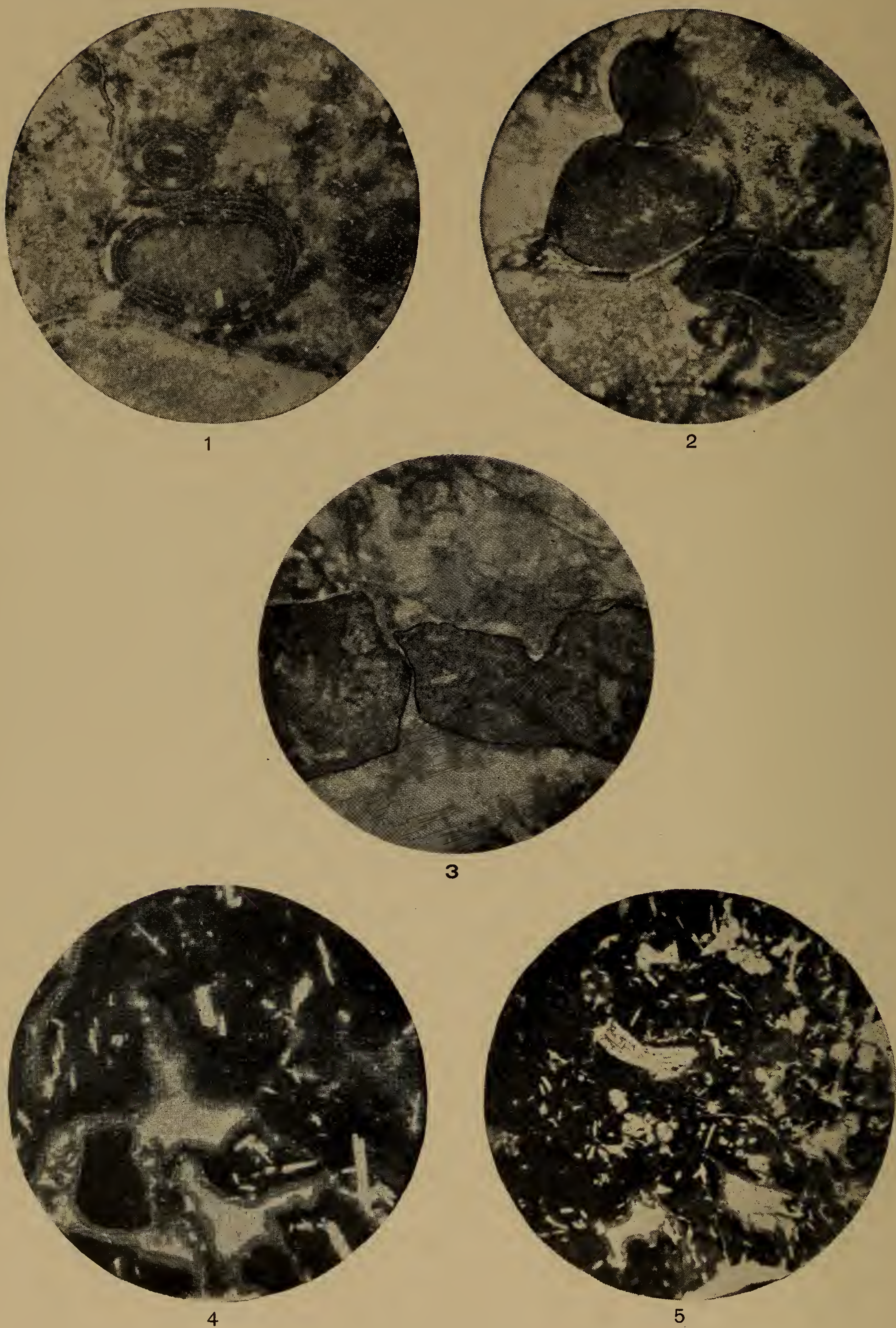
THIN SECTIONS OF MATERIAL FROM GREENFIELD AND MERIDEN "ASH BED"



THIN SECTIONS OF MATERIAL FROM MERIDEN "ASH BED"

Plate 8.—*Thin Sections of Material from Meriden "Ash Bed."*

Figure 1.—Two greenish brown banded spherulites. The larger is radiate-fibrous in each band and in the center. They are in a glass fragment, which is devitrified precisely as the center of the large spherulites It contains a thread of yellow glass. At the bottom, below the edge of the glass fragment, is a calcite and calcedony deposit which cements the fragments. Magnified 35 times. Meriden "ash bed." See page 74.

Figure 2.—Brown spherulite and glass drops in a colorless calcified glass breccia. The drops are affected by a perlitic cracking, and the center has contracted slightly from the curved films which have cracked off, and these have broken and slipped by each other. The drops and the center of the spherulite have suffered granular devitrification, which extends to the glass outside the drops. In the outer layers of both it is transversely fibrous. Magnified 35 times; crossed nicols. Meriden "ash bed." See page 74.

Figure 3.—Shattered glass, with the fragments showing a fine fibrous devitrification, which is in most places transverse to the surfaces of the fragments, and is therefore subsequent to the shattering. The fibers are like those of the spherulites, are radiate from many centers, and show the black cross many times repeated. The fragments are cemented by a plagioclase calcite mixture showing at the bottom of the slide. The whitish part is calcite. Meriden "ash bed." Magnified 35 times; crossed nicols. See page 74.

Figure 4.—Dark brown, wholly non-polarizing glass with many plagioclase rods changed to granular calcite. A lighter band of yellow glass borders the collapsed and half collapsed steam holes, in one of which a glass thread is drawn out and bent upon itself. Directly below a cavity is full of glass threads. From a great block of pure glass on the bluff above the blasting at the Meriden "ash bed." Magnified 20 times. See page 73.

Figure 5.—Another portion of the slide shown in figure 4. The deep brown glass graduates into a light yellow brown, the latter dusted by ferrite grains and showing the minute fissuring which causes the greasy luster. A large, fresh diopside has been bent about 15 degrees without fracture. This must have been done during the deformation of the solid glass. Magnified 20 times. See page 73.

Plate 9.—*Thin Sections of Material from Meriden "Ash Bed" and north Locality.*

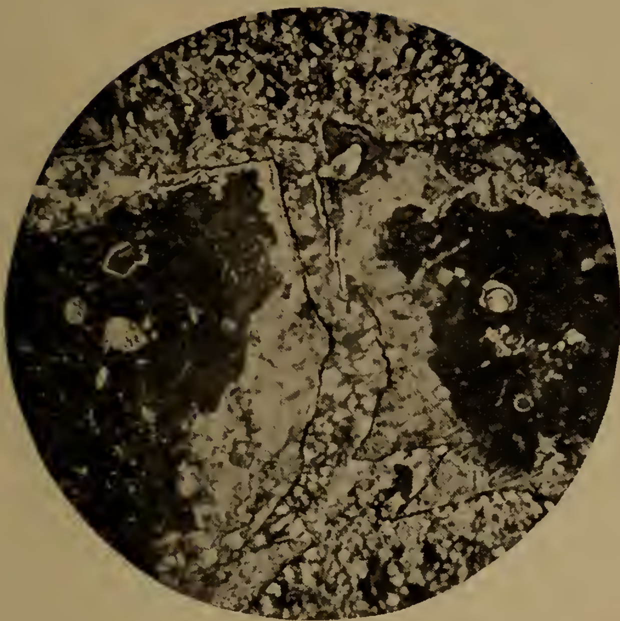
Figure 1.—Mixture of sand and glass fragments from the Meriden "ash bed." The sand at the top runs down between two fragments, which are red brown glass at center, much changed to calcite, with lighter devitrification border of a yellow color, which is altered to a fibrous plagioclase, and an outer cord of highly refringent glass, which is broken and moved in places, letting the glass out among the sand grains. This is best seen on the inner border of the right-hand piece. Along the upper edge of this piece is a band of colorless glass (dark in the photograph), which is changed to calcite. There is a curve in the border line above the center where a spherulite has slipped out. The right-hand piece shows two spherulites, the left-hand one, several serpentinized olivines. Magnified 20 times. See page 75.

Figure 2.—Sand cemented by glass into a hard quartzite. The slide has been treated with HCl and KHO, and the brown portion of the glass has been in part dissolved, so that threads cross the empty spaces and join the refringent cord of glass that bounds each sand grain. Near basal bed at the Meriden "ash bed." See page 75. Magnified 85 times.

Figure 3.—Fragment of black aphanitic diabase melted at the border into a blebby glass and with a thread of glass going out from it. In breccia in throat of the mud volcano at the north locality at Meriden. See page 76. Magnified 20 times.

Figure 4.—Rare fragment of amygdaloid in glass breccia. From north locality at Meriden. See page 77. Magnified 28 times.

Figure 5.—Several varieties of trap in one slide ; (1) aphanitic trap, with large fragments of altered orthoclase, showing that it solidified after the introduction of foreign material and was then shattered and carried upward and mingled with other varieties, (2) amygdaloidal trap, (3) hyalopilitic trap in center. North locality at Meriden. See page 78. Magnified 20 times.



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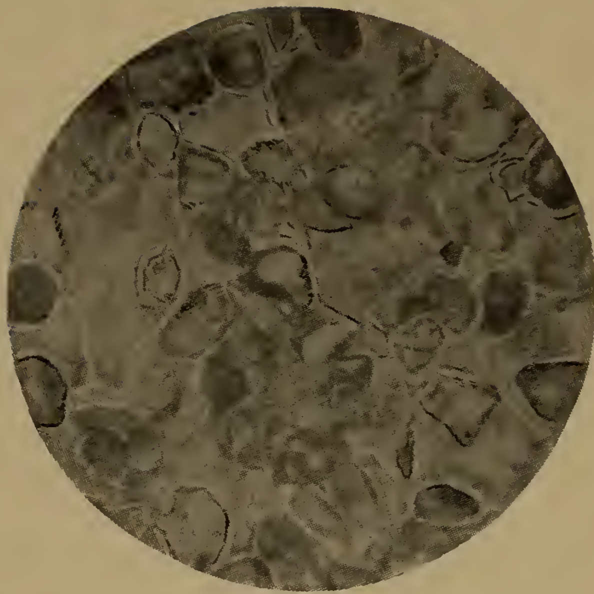

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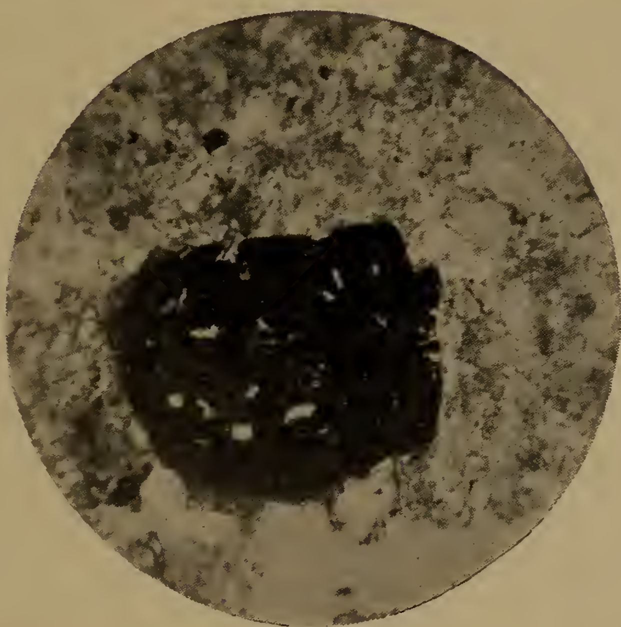

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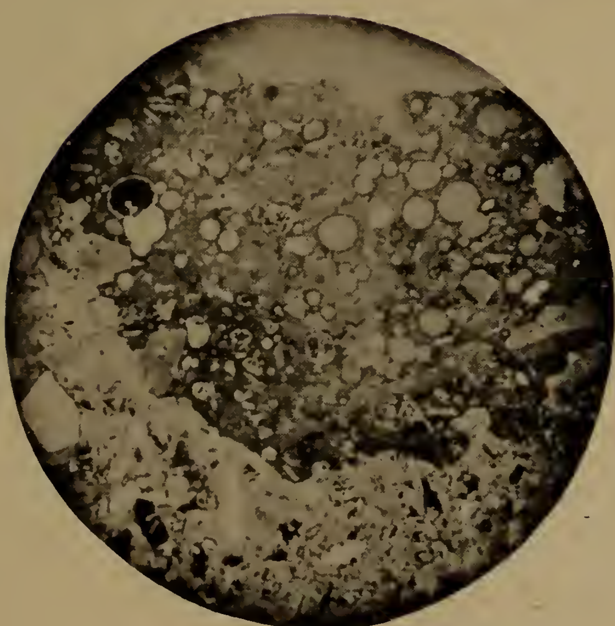

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THIN SECTIONS OF MATERIAL FROM MERIDEN "ASH BED" AND NORTH LOCALITY

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SHEETFLOOD EROSION

BY W J MCGEE

(*Presented before the Society August 22, 1896*)

CONTENTS

DEFINITIONS.

Commonly, running water gathers into streams and corrades channels; exceptionally, running water spreads into sheets of limited or unlimited width, and, by a combination of erosion and deposition, produces plains.

Pure water flowing over a smooth indestructible surface does not move as a uniform film: if the surface is broad the sheet differentiates into parallel streams of greater depth and relatively rapid flow, separated by shallower bands of relatively sluggish flow; and at the same time both streams and intervening bands differentiate into series of transverse waves which move forward more rapidly than the body of the differentiated sheet. The tendency of flowing water to divide into streams is well known; it is undoubtedly by reason of this tendency that running waters commonly flow in streams which cut channels and eventually fashion most of the lands of the earth. The tendency of flowing water to break up into transverse waves is not so well known, though beautifully exemplified in sluices for irrigation or for bringing logs and lumber down from mountains (where it is the succession of waves which prevents the sluice from clogging and equalizes the movement of the floating load); it is of subordinate importance geologically.

Under certain conditions, sand-laden water flowing over an erodable plain tends at first to divide into parallel streams like those of pure water on an indestructible surface, yet, since the streams formed in this way at once begin to scour and overload themselves and thus check their own flow, this tendency is soon counteracted and the water is distributed again; so that the ultimate tendency is toward movement in a more or less uniform film or sheet. This tendency is well known to laymen in those regions in which it prevails, but it seems not to be generally recognized among geologists. Colloquially a moving water-body of this type is sometimes known as a "wash;" but since the term is commonly applied primarily to the product and only secondarily to the agency, and since it is usually restricted to limited, though broad, channels (*e. g.*, in San Francisco wash), it seems desirable to use some other designation for the water-body; and the term *sheetflood* has come into use in notes and in conversation.

Thus there are in nature two strongly contrasted types of moving water bodies, namely, (1) streams, and (2) sheetfloods. The first type is characterized by a tendency toward concentration in narrow and relatively deep bands which quickly cut channels for themselves; the second is characterized by a tendency to spread widely in relatively shallow sheets. The second is logically coordinate with the first as a geologic agent. In a general way streams prevail in humid regions, sheetfloods in arid regions, though streams occur locally in arid lands, while it seems probable that sheetfloods occur under certain conditions in nearly all lands, howsoever humid.

Sheetflood Work in the Sonoran District.

FEATURES OF THE DISTRICT.

Location.—Sheetflooding is characteristic of the broad expanse of plain and mountain in southwestern Arizona and western Sonora (Mexico), stretching from the Sierra Madre to the gulf of California, and lying between Gila and Yaki rivers. In physical characteristics and geologic history this territory forms part of Powell's great province of "Basin

Ranges,"* constituting a considerable part of that portion of the province characterized by "Open Basins;" but the district is so distinctive that, for purposes of description at least, it may be set apart as the *Sonoran district.* It corresponds approximately with the region known among the Mexican inhabitants as Papagueria, or land of the Papago Indians.

The Sonoran district slopes from the high Sierra of Mexico and the Mogollon escarpment at its northern extremity to tide level in the gulf of California. To the casual observer traversing its expanse it seems a region of mountains, for rugged buttes, mesas, and sierras are always in sight and usually dominate the landscape; but more careful observation shows that it is primarily a plains region, since fully four-fifths of its area consists of plains, hardly one-fifth of mountains, and the elongated sierras and scattered buttes are nearly always flanked by vast tracts of lowland. The mountains range up to 6,000 or 6,500 feet above tide in the interior (imposing Baboquivari, southwest of Tucson, measures 6,798 feet) and still greater altitudes toward the Sierra Madre; the intermontane plains rise gently from sealevel to 3,500 or 4,000 feet,† while the buttes and sierras may rise anywhere from 100 to 4,000 feet above the circumscribing plain. The mountains are notably rugged, abounding in lofty precipices, vertical and sometimes overhanging cliffs, knife-edge aretes, and leaning (apparently or actually) picachos, and they rise with remarkable abruptness from the smooth plains, so that, to the casual observer, they seem an archipelago of rocky peaks rising from an ocean of desert sands. Though monotonously smooth, partly by contrast with the rugged mountains, the plains slope gently away from the mountains and merge in flat-bottomed valleys leading directly or deviously toward the sea, so that the entire surface, with the exception perhaps of a few playas near the coast, drains seaward. In the valleys occupied by washes (rivers during the wet seasons, sand wastes during most of the year) the grades may be as low as 20 or even 15 feet to the mile; over the average plain the slope is 50 or 75 feet to the mile, and on the great apron-like foot-slopes pushing among the aretes and lateral spurs of the larger sierras the grade may be 100, 200, even 300 or more feet to the mile.

Climate.—The Sonoran district is excessively hot and arid. Yuma, noted as the hottest station in the United States, is in its northwestern corner, and while records are lacking, it is probable that Caborca and Hermosillo are considerably hotter; the rainfall in the Sierra may reach 15 or 20 inches,

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* National Geographic Monographs, vol. i, 1895, pp. 95-98.

† Captain D. D. Gaillard, of the International Boundary Commission, writes: "The sacred peak of the Papago, Baboquivari, is 6,798 feet above mean sea level of San Diego bay. The lowest part of the valley on the east of this peak (called the "Sasabe flat") is about 3,200 feet above the same datum plane, while the lowest part of the valley on the west of the peak (called the "Moreno flat") is only about 2,300 feet above the plane of reference" (official letter dated February 6, 1896).

but the meager records in even the most fertile valleys in the foothills seldom rise above 10 inches, while the average over the interior probably falls below 5, and may be no more than 2 or 3 inches during the year. There are two nominally wet seasons, occurring respectively about midwinter and midsummer. The midwinter precipitation is generally the heavier and the more widely distributed, but both in summer and in winter the greater part of the rainfall occurs in local storms. Snow falls on the Mogollon and the Sierra, remaining half the year on a few of the highest points; to this fact the perennial character of some of the northern tributaries of the Gila and the stronger branches of the Yaki may be ascribed. During the occasional drizzles of the wet seasons the scanty moisture is chiefly absorbed by the sun-baked earth, so that floods do not ensue, though the spring-fed streams may rise by reason of the diminished evaporation; during the moderate storms that occur here and there from year to year torrents are produced which rush tumultuously down the slopes and become potent geologic agents, and during the great storms occurring from decade to decade or from century to century whole plains are flooded; yet so dry are air and earth that the deluge is absorbed within a few miles or scores of miles. Thus, although the entire surface slopes seaward, no living water reaches the sea between the Colorado and the Yaki, 700 miles away.

By reason of heat and aridity the Sonoran district is desert or subdesert throughout; the vegetation is too scant, stunted, and scattered to protect the surface from storms; the meager flora forms little or no humus, and thus there is no soil and little of that chemic action initiated by vegetal growth and decay. Through a combination of biotic conditions of great significance the vegetal life and the sedentary animal life are concentrated in scattered colonies with bare earth between, and the colonies collectively form but a small fraction of the total area. Thus the region is one in which physical agency operates directly, with little aid or obstruction from the biotic agency always present and often predominant in humid districts.

Since the waters of the Sonoran district never reach the sea the territory is complete in itself as a geologic province; the storm waters gather detritus in the mountains and transport it into the valleys, but their agency is limited to shifting the rock matter from one point to another in the same vicinity, and thus degradation and aggradation go hand in hand, and gradation is completed within the district.

Topography.—At first sight the Sonoran district appears to be one of half-buried mountains, with broad alluvial plains rising far up their flanks, and so strong is this impression on one fresh from humid lands that he finds it difficult to trust his senses when he perceives that much of the valley-plain area is not alluvium, but planed rock similar to or identical with that constituting the mountains. To the student of geomorphy this is the striking characteristic of the Sonoran region—the mountains rise from plains, but both mountain and plain (in large part) are carved out of the same rocks. The valley interiors and the lower lowlands are, indeed, built of torrent-laid debris, yet most of the valley area carries but a veneer of alluvium so thin that it may be shifted by a single great storm. Classed by surface, one-fifth of the area of the Sonoran district, outside of the Sierra and its foothills, is mountain, four-fifths plain; but of the plain something like one-half, or two-fifths of the entire area, is planed rock, leaving only a like fraction of thick alluvium. This relation seems hardly credible. During the first expedition of the Bureau of American Ethnology (in 1894) it was noted with surprise that the horseshoes beat on planed granite or schist or other hard rocks in traversing plains 3 or 5 miles from mountains rising sharply from the same plains without intervening foothills; it was only after observing this phenomenon on both sides of different ranges and all around several buttes that the relation was generalized, and then the generalization seemed so far inconsistent with facts in other districts that it was stated only with caution even in conversation. During the 1895 expedition a skilled student of geomorphy (Mr Willard D. Johnson) was added to the party, partly in the hope that observation in this direction might be extended and verified or corrected. Even then the observations and inferences seemed hardly worthy of trust until the shores of the gulf of California in Seriland were examined and the superb section from Punta Ygnacio to Puerta Infierno was found to exhibit clearly the inferred relation. "A quarter of this 15-mile exposure is the current-built point, another quarter cuts butte or range of igneous rock or ancient granite, while the remaining half traverses typical intermontane plain in cliffs of 20 to 50 feet, and fully 5 out of the 7½ miles of the low cliff reveal the substratum of planed granite beneath a torrential veneer, while there is more of alluvium-free granite than of graniteless alluvium."* Sierra de Tonuco, lying a few miles outside the northeastern corner of Seriland,† is a typical mountain mass of the Sonoran district; it is a deeply furrowed block of semi-metamorphic limestone resting on an inclined table of slightly schistoid granite; its crest is perhaps 2,500 feet above the plain, and its upper three-fifths is limestone; its base appears to be heavily burdened with taluses of limestone and granitic debris, but occasional arroyas cut through these aprons and show that they are not of great depth. These rubble-cumbered slopes pass within a fraction of a mile into a lowland plain so

* National Geographic Magazine, vol. vii, 1896, pp. 127, 128.
† Map of Seriland, op cit., pl. xiv.

smooth that, except where outlying granite buttes rise from its expanse, it may be traversed by wagons in any direction; yet for 5 miles from the mountain base on northeast, north, west, south, and southeast the wheels grind over granite half the time, while on the east the alluvial veneer appears barely to conceal the granite over an area larger than that occupied by the sierra. In the northeastern portion of the Seriland map over a dozen buttes are shown rising sharply from the subdesert plain, and though these lie almost in the delta of Rio Bacuache, analogy with similar buttes a few miles further northeastward, which were carefully examined, indicates that they are not scattered island summits, as their appearance suggests, but merely knobs rising from a baseleveled plain of granite traversed somewhere by an ancient valley a few hundred feet deep. Again, 5 miles southeast of Puerta Infierno the tide-carved coast cuts a typical granitic butte a hundred feet high and as many yards across, rising sharply from the inclined foot-slope of Sierra Seri, yet the rugged-faced knob is seen to surmount a granite pediment nearly half a mile across in the line of section.

It is to be remembered that the surface and structure of the district are known only through two expeditions, each traversing it twice; but so far as the observations go they indicate that the vast plains diversified by scattered sierras and buttes do not represent an alluvium-buried mountain land so much as a planation level with a few monadnocks still surviving.

Geology.—The structural geology of the Sonoran district is too little known to warrant detailed description. In a general way the rocks appear to be (1) ancient granites, (2) partially metamorphosed limestones, shales, etcetera, and (3) moderately old igneous sheets with associated tuff beds.

The granite is sometimes quite schistose, again massive and homogeneous, frequently cut by veins and dikes. Where it reveals structure the trends are approximately meridional. Originally (so far as can be judged) it was a floor on which the sedimentaries were laid unconformably; now it is deformed chiefly by upbending into meridional ridges with culminating nodes forming the nuclei of sierras. There are no data concerning its age except the structural relation showing it to antedate the clastic strata.

The limestones, shales, and other clastics are apparently of considerable aggregate thickness, limestones predominating in the south and shales in the north. Commonly they are highly inclined; often they are folded, somewhat Appalachian-wise, into meridional ranges greatly reduced by degradation. Sometimes, as in Sierra de Tonuco, and also in Sierra de Cabórca (where the trend is locally latitudinal), the limestones seem to be only slightly inclined. Commonly the rocks are decidedly metamorphosed, the limestones into marble, the shales into phyllitic and other schists, slates, etcetera; yet sometimes, as in the sierras just noted the alteration is slight. In Sierra de Caborca the limestone is highly silicious (intermixed and interlaminated with silicious silt) and weathers brown, highly vesicular, and ferruginous, so as to be mistaken locally for lava. Collectively the clastic rocks seem to be corrugated extensively, and the harder beds, together with the nucleal granite ridges and nodes, form the scattered sierras characteristic of the district; but the region has suffered profound degradation whereby much, probably the greater part, of the clastic mass has been carried away. Locally, in certain of the sierras, the topographic configuration expresses the structure, as Johnson's surveys admirably show; throughout the plains and fully half of the mountain area (*i. e.*, in nine-tenths or more of the district) there is no visible relation between structure and configuration. No general faulting and monoclinal deformation such as is considered characteristic of the Great Basin was detected. The age of the clastics has not been determined, but there is some reason for correlating them with the sedimentaries of eastern Mexico and certain of the metamorphics of California, and regarding them as Jurassic and Cretaceous.

In parts of the district igneous rocks and tuffs prevail, concealing the ancient granites and the clastics and forming most of the buttes and lower ranges as well as portions of the greater sierras; and elsewhere similar materials are found here and there, sometimes throughout considerable areas. Sometimes the igneous rocks are apparently involved with the clastics, and in general they seem to have suffered degradation conformable with that of limestone and schist and granite, so that the origin of the greater part of them would seem to date back nearly to the close of the principal deposition period. Occasionally newer looking and less eroded lavas and tuffs are found, and in the western part of the district there are coulees and lapilli beds, particularly about the volcanic peak Pinicate; but modern or even late Tertiary vulcanism would seem to be quite local and exceptional.

Hydrography.—Viewed as a unit, the Sonoran district is a great plain sloping from the high Sierra to the sea and relieved here and there by minor ranges and masses usually trending in north-south directions; but viewed in greater detail it may be considered by the student, as it is by the Indian, Mexican, or American layman, as an assemblage of drainage basins or "valleys." In a general way the "valleys" lie between the parallel ranges, those north of the subcontinental divide (which coincides approximately with the international boundary) sloping toward the Gila, those beyond the divide sloping southward; but in passing westward each "valley" lies lower than its neighbor, and in the western part of the district the ranges are often interrupted and the "valleys" open one into another directly toward the sea, while in all portions the larger water-lines frequently trench the sierras and unite two or more "valleys" in a single drainage basin. Typically the "valley" is simply a vast elongated plain tilted sharply upward into bounding sierras on both sides and around one end; the plain is slightly concave, and if the slope exceeds say 15 or 20 feet per mile, its center is marked by a "wash"—a torrent perhaps a mile wide after the great storm, a sterile sand waste at other times; and the upturned rim is carved by labyrinths of barrancas, many of which unite at the mountain base to form shallow arroyas meandering the plain, but seldom reaching its center. Thus the typical "valley" is waterless save during storms, and its ephemeral waterways are multitudinous in the bounding mountains and few or none in its flattened interior. In the eastern part of the district, where the parallel ranges are higher and lie closer together, some "valleys" carry permanent streams northward and southward from the subcontinental divide toward, and at storm time into, geographically great but hydrographically puny rivers—the Gila in Arizona, and the Altar (or Asuncion, or Pitiquito, or Magdalena, or San Ygnacio) and the Sonora, as well as the northern branches of the Yaki, in Sonora. These "valleys" occupied by permanent rivers are not typical for the district, in that they are rather broadly flattened V-shape than concave in profile; yet they vary from normal valleys in that water is scanty or absent in the depths and increases with the ascent of the waterways and culminates well toward the summits. Such "valleys," or the greater waterways by which they are connected, ultimately trend westward through the bounding ranges and down the general slope toward the sea—a bourne which they (excepting a tributary or two of the Gila and two more of the Yaki well toward the high Sierra) never reach. So the important constituent elements of the district are valley-plains, bounded by barranca-scored mountains and sometimes faintly inscribed with drainage lines which are nominally rivers but actually sand wastes during 360 days of the average year; and the mountain is far subordinate in importance to the valley-plain, while the "river," though a necessary descriptive term, is little more than an empty name.

The general topographic relation of "valley," mountain, and "river" is modified and often masked by a subordinate relation growing out of a northeastward migration of the divides. It is to this migration that the westward deflection of the principal rivers is due, and it is to the same cause that the union of neighboring "valleys" into irregular basins must, in most instances, be ascribed. So common is this tendency that, except in the foot ranges of the high Sierra, few of the drainage basins are complete and symmetric; few of the outlying sierras have escaped trenching by the retrogression of arroyas opening westward or southwestward, and many of the divides, main as well as minor, have been shifted from the rims well into the interiors of the valley-plains.

Geologic development.—The observations of the two expeditions by the Bureau of American Ethnology yielded certain inferences concerning the structure, geomorphy, and geologic history of the district, and these in turn yielded certain generalizations; and as a supplement to the empiric description they are worthy of statement for the purpose of making clearer the features of the district, though it is to be remembered that they constitute a series of field hypotheses, probably valid in the main though requiring elaboration and minor modification with further field-work. The first inference is that the clastic rocks represent a thick and practically continuous series of deposits laid down on a granitic floor, the series growing finer and more calcareous southward. The second inference is that about the close of the period of deposition vulcanism was initiated, whereby considerable sheets of lava and tuff were produced. The third inference is that toward the close of the period of vulcanism extensive deformation occurred, chiefly as east-west compression, with consequent development of meridional corrugations, and it is deemed probable (though there is little explicit evidence on this point) that the cycles of (1) deposition, (2) vulcanism, and (3) deformation occurred in this order, yet overlapped to such an extent that deformation perhaps began before deposition entirely ceased and while sporadic vulcanism also persisted. The fourth inference is that the massif produced in this way stood at moderate altitude for a long period, including approximately the Eocene and the earlier half of the Neocene; that a large part of its volume was degraded; that the surface was planed to an approximate baselevel, relieved by ridges and masses of the monadnock and catoctin types, usually of harder layers but sometimes marking broader divides, and that during this vast period the drainage basins were outlined and developed. It is deemed probable that during much or all of this period the precipitation was greater than now, so that the district throughout was one of degradation, and so that the drainage basins were of the normal dendritic type, veined by rivers occupying broad yet essentially V-shape valleys; and it is considered probable also that the basin-limiting sierras were less rugged than now. The final inference is that the period of symmetric degradation was terminated by general southwestward tilting due to uplift in the northeastern portion—the uplift that resulted in the making of the Sierra Madre in Mexico and the high plateaus in the United States, and in the birth of Colorado river; that this geographic change was accompanied by a meteorologic change, chiefly diminution of precipitation to such extent that the rivers shrunk and ceased to carry detritus or even to flow into the sea, and that the storm freshets flowing northeastward were paralyzed while those flowing southwestward were relatively stimulated (both in high and cumulative degree because of the delicate adjustment between pecipitation and absorption), so that every divide in the district began migrating northeastward. It is deemed probable that the tilting began somewhat gradually late in the Neocene, and thus that the transformation in the face of the district took place rather slowly. It is also deemed probable that essentially the present attitude has now been maintained for a long time, though the tilting is doubtless yet in progress at a slow rate. It may be noted that the records of neighboring districts, so far as known, are consistent with that interpreted for this district.

STREAM EROSION IN THE DISTRICT.

Charactor of streams.—The current maps of the Sonoran district commonly represent a considerable number of rivers gathering from many tributaries in the mountains and flowing northward into the Gila or southward and westward into the Altar and Sonora or directly into the gulf. Better maps based on actual surveys, such as those of the General Land Office in the United States, show multitudes of small streams flowing down the mountain slopes and either ending on the plain or uniting in rivers which wander toward some principal waterway and end blindly; but the general maps express hypotheses based on the behavior of streams in humid lands, and even the best maps represent the sand washes produced by great storms in lieu of permanent water. In the more elevated eastern part of the district, and during the rainy seasons, especially that of winter, when the storm water in the mountains is supplemented by melting snows, most of the sand washes are, indeed, converted into streams, which, although shallow, are rapid and even torrential, and carry vast volumes of sediment-charged water down the slopes; but throughout most of the territory the sand washes are hardly wetted during the normal rainy season, and are transformed into torrents only during great storms or cloud-bursts occurring at intervals of years or decades. So the map representing sand washes as rivers is misleading unless its purely conventional character is clearly understood. Although the aggregate stream length represented in such a map is considerable, perhaps several times greater than the aggregate length of the streams actually flowing on a given date during the wettest season, yet during the dry season the aggregate length of actual water lines is reduced to a minute fraction of the aggregate length of sand wash, and nearly all of the channels are dry. So the stream of living water is an exceptional, indeed an exceedingly rare, feature in the Sonoran district, and is hardly known save in its more elevated eastern portion.*

Sources of streams.—The sources of stream water are, as usual, three—(1) melting snow on the high Sierra and the Mogollon, (2) ground-water appearing as seepage or springs in the deeper valleys, and (3) the product of rains. The first of these sources might be neglected, save that it contributes (*a*) directly to the longer rivers, San Pedro and Santa Cruz in Arizona, and Altar, Magdalena, Bacuache, Sonora, San Miguel, and the main and minor branches of the Yaki in Sonora, and (*b*) indirectly through ground-water to these and other streams during a part of the year.

The ground-water is of considerable importance as a source of streams, partly since its flow is moderately steady, and its tendency is thus to maintain the stream as such and to enable it to continue corrasion and transportation, albeit feebly, throughout the year. In the mountain gorges the ground-water commonly emerges as permanent or temporary springs, while in the alluvium-lined valleys it simply seeps through the sand, generally below the surface, though sometimes in a slender streamlet winding through the broad sand wash. Among the rocks of the mountains the ground-water movement is conditioned as in humid lands, but in the broader valleys it is conditioned by a variety of factors, including the conformation of the alluvium-lined basin with its various arms and interruptions, as well as by the rate of evaporation, etcetera. Thus the alluvial mass and the adjacent hard rocks are wetted or saturated during the rainy season, and the water percolates down the slopes along lines generally corresponding with those of surface drainage; and wherever the surface drainageway is exceptionally deep, there the ground-water most frequently emerges to flow for rods or miles, or until evaporated or reabsorbed by the sands. So it happens that water may often be found by digging in the dry sands of a wash; that a nominally permanent stream may appear, disappear, and reappear half a dozen times in the course of a day's journey down a single storm-fashioned wash, and that the rippling streamlets lengthen during the night and in cool or cloudy weather and shrink during the day and the heat, when evaporation culminates.

It is by reason of this relation between land surface and ground-water surface, in conjunction with the characteristic migration of divides, that a considerable part of the Sonoran district is habitable by man, for it is in the narrow gorges produced by the retrogressive erosion trenching the

* The bounding rivers, Gila and Yaki, are maintained by tributaries from without the district.

ranges that the ground-water reaches or approaches the surface so that settlements can be maintained.

The chief source of stream water is the sporadic storm, especially the thunder-gust or cloud-burst, which fills old channels and gouges out new ones, though the flow may last but a few minutes, and seldom continues more than a few hours. In the sierras the slower drizzles produce stream floods which sometimes find their way out on the valley-plains, though the drizzle on the plain commonly does no more than wet the surface or produce feeble sheetfloods; and on the broader plains only a relatively small part of even the heaviest rainfall ever collects in streams.

In brief, the streams of the district are strikingly short and small in proportion to the area, and only less strinkingly few and feeble in proportion to the scant precipitation.

Streamways and stream-work.—In the sierras the permanent streams are slender threads of water slipping over ledges, now gathering in tinajas,* and again disappearing in fissures or gravel pockets at the bottoms of rugged barrancas; and the barrancas dividing narrow aretes are exceptionally parallel and close laid, while it is the combes or amphitheaters in which the barrancas head, in conjunction with the peaks in which the aretes join the crests, that produce the characteristic sierra profile. Most of the multitudinous barrancas are supplied only by storm torrents, and these usually end about the base of the sierra, the margin of the valley-plain; it is only the deeper and longer barrancas that send arroyas or permanent channels far enough over the plain to unite with other waterways in dendritic systems; and it is partly for the reason that most barrancas end at the plain that their remarkable parallelism is maintained. Outside the sierras the typical channel is at first a rugged or flat-bottomed barranca cut in the country rock; it soon diminishes in depth and increases in width and becomes lined with boulder beds; still further down stream it changes into a broad, steep-banked arroya cut in alluvium and burdened with gravel beds or sand sheets; and it finally ends in an alluvial fan, usually of imperceptible slopes miles in length and furlongs in width. If the stream is permanent it is, in its low-water stage, but a thin ibbon of water rippling over the rocks of the upper course or the sands of the middle course. The streamways are notable, first, for high grades, and, second, for the width of their channels, which may exceed that of the Ohio, or even that of the Mississippi, for a stream less than 50 miles long; but during most of the year nine-tenths of the few streamways are broad wastes of barren sand, the most forbidding lines of the desert, often littered with skeletons of famished stock.

* Natural bowls, or water-pockets; defined in Science, new series, vol. iii, 1896, p. 494.

The character of the channels expresses well the characteristics of stream erosion: In the sierras the storm torrents gather loosened rock masses (there is little disintegrated detritus and still less decomposed rock matter on the steep slopes), hurl them down the cliffs and hurry them through the barrancas, bursting them asunder and knocking loose other masses on the way; toward the base of the sierras the larger boulders lodge, to be removed and reduced during later storms, while the pebbles and finer debris are swept further. Then general or local conditions either spread the torrent into a sheetflood, or else maintain the stream character; and in the latter case cobbles and pebbles are laid down after much trituration, the sand is carried far, scouring the channels as it goes, and finally nothing coarser than silt is borne by the diminishing flood, which is constantly robbed by dry earth below and drier air above; the silt burdens the flood without giving much aid in corrasion, and it gradually expands either into a labyrinth of interlacing channels or into a sheetflood, when evaporation and absorption rapidly sap the strength of the torrent until it ceases to be. It is significant that despite the high declivity of the barrancas the freshet torrents are often surprisingly clear, evidently by reason of the dearth of comminuted and lixiviated detritus, so that the streams are often underloaded and thereby enfeebled as erosive agents.

The streamwork in the district is notable partly in that it is exceptional in occurrence, partly in that it is reduced and rendered subordinate by the tendency of the streams to pass into sheetfloods with diminishing declivity; for most of the barranca torrents are transformed at once on reaching the valley-plain, while the sand-lined channel of the typical arroya is but a sheetflood of limited width. So strong indeed is the tendency toward transformation that it is only in the few streams of permanent supply and in the valley-plains oversupplied by exceptionally extensive drainage basins that definite channels are maintained.

SHEETFLOODING IN THE DISTRICT.

Character of sheetfloods.—In distribution the streams are mainly confined to the sierras, including the Sierra Madre and the higher foot-ranges as well as the lower outlying ranges and masses and the isolated mesas and buttes, and are local and exceptional in the valley-plains, while half the vast valley-plain area is the area of sheetflooding. Although there is a general increase in precipitation with altitude throughout the district, the cloudburst and drizzle usually affect both sierra and valley-plain; and in such cases the plain is flooded by the direct rainfall as well as by drainage from the sierra. The character of the flooding is known from direct observation, from indirect observation on flotsam, and from consistent lay testimony.

During the 1894 expedition a moderate local rain occurred while the party were at a Papago rancheria near Rancho de Bosque, some 15 miles north of the international boundary at Nogales; the rainfall was perhaps one-fifth of an inch, sufficient to moisten the dry ground and saturate clothing despite the concurrent evaporation, and was probably greater in the adjacent foothills of Santa Rita range. The road was sensibly level, having only the 20-feet-to-the-mile grade of Santa Cruz valley; it ran across the much stronger slope from the range toward the river, and an arroya embouched from low terraciform foothills not more than 200 or 300 yards up the slope. Thus the arroya opened not on a perceptible fan but on a sensibly uniform plain of sand and silt with occasional pebbles sloping perhaps a 150 feet to the mile. The shower passed in a few minutes and the sun reappeared, rapidly drying the ground to whiteness. Within half an hour a roar was heard in the foothills, rapidly increasing in volume; the teamster was startled, and set out along the road up the valley at best speed; but before he had gone 100 yards the flood was about him. The water was thick with mud, slimy with foam, and loaded with twigs, dead leaflets and other flotsam; it was seen up and down the road several hundred yards in either direction or fully half a mile in all, covering the entire surface on both sides of the road, save a few islands protected by exceptionally large mesquite clumps at their upper ends. The torrent advanced at race-horse speed at first, but, slowing rapidly, died out in irregular lobes not more than a quarter of a mile below the road; yet, though so broad and tumultuous, it was nowhere more than about 18 inches and generally only 8 to 12 inches in depth, the diminution in depth in the direction of flow being less rapid than the diminution in velocity. The front of the flood was commonly a low, lobate wall of water 6 to 12 inches high, sloping backward where the flow was obstructed by shrubbery, but in the open curling over and breaking in a belt of foam like the surf on a beach; and it was evident that most of the water first touching the earth as the wave advanced was immediately absorbed and as quickly replaced by the on-coming torrent rushing over previously wetted ground. Within the flood, transverse waves arose constantly, forming breakers with such frequency as to churn the mud-laden torrent into mud-tinted foam; and even when breakers were not formed it was evident that the viscid mass rolled rather than slid down the diminishing slope, with diminishing vigor despite the constant renewal from the rear. Such were the conspicuous features of the sheetflood—a thick film of muddy slime rolling viscously over a gently-sloping plain; and this film was a transformed stream still roaring through a rugged barranca only a few miles away. A special feature soon caught attention: On looking across the flood it was seen from the movement of waves and flotsam that the rate of flow was generally uniform, a little more sluggish about the mesquite clumps, a little swifter over the interspaces; but now and then a part of the sheet (usually between and below mesquite clumps or slight elevations by which the current was made to converge) began to move more rapidly, when almost immediately the flotsam would shoot forward at twice or thrice the ordinary rate, the flood surface would sink toward the upper end and swell toward the lower part of the rush line, while the roar would rise above the rustling tumult of the more sluggish waters; within 50 feet or 50 yards the swelling rush would be churned into foam and rise several inches above the general level of the flood, and then the waters would diverge and slacken and quickly mingle with the general sheet; sometimes the crest of a delta or fan would show through or above the water at the lower end of the rush, and would push up stream through growth chiefly at its upper end; but in any event the whole process of the gathering and respreading of the waters commonly lasted but a few seconds, or perhaps a minute or two, and left but a faint trace in unusual rippling of the flood. So common were these rushes that two or three or even half a dozen might be within the field of vision at the same time—some just starting, some dying away. For perhaps five minutes the sheet-flood maintained its vigor, and even seemed to augment in volume; the next five minutes it held its own in the interior, though the advance of the frontal wave slackened and at length ceased; then the torrent began to disappear at the margin, the flow grew feeble in the interior, the water shrank and vanished from the margin up the slope nearly as rapidly as it had advanced, and in half an hour from the advent of the flood the ground was again whitening in the sun, save in a few depressions where muddy puddles still lingered.

The after effects of the flood were not conspicuous, though significant. The most striking effect was the accumulation of flotsam, chiefly twigs and branches, against the upper sides of clumps of shrubbery, ant-hills, ground-squirrel mounds, and other elevations; and from these the extent of the flood could be traced even beyond the limits of vision, showing that its width was at least one and perhaps two or three miles, and that it nearly blended with other similar floods emerging from neighboring barrancas in the mountains and arroyos in the foot-slopes. A less striking effect was the accumulation of a nearly continuous film of sediment, chiefly fine sand or silt, hardly distinguishable after drying from the general surface deposit, with which it undoubtedly soon blended. This film was usually an inch or less in thickness, though sometimes it lined depressions to depths of several inches. A highly significant effect was found on examining the track of one of the more violent rushes within the flood: At the upper end this was a gully reaching two feet in depth and one or two yards in width, newly gouged in the gravelly and sandy silt of the plain; at the lower end it was an elongated delta or fan, composed chiefly of sand but containing occasional pebbles (which were not borne by the sheetflood, and must accordingly have been washed out of the gully). A score of other gullies and deltas were seen, some well developed, some nearly obliterated, and it seemed clear that the well developed examples were only those produced toward the end of the freshet, the earlier examples having been masked or obliterated by the later flooding. These distinctive marks of the sheetflooding were distributed as extensively as the flotsam heaps, and in like manner were found on the plains below neighboring arroyos

On traversing a characteristic torrential apron stretching southward from the southern end of Baboquivari range toward the great arroyo known as Rio Seco, in northern Sonora, the track of a still more extensive sheetflood was crossed, its traces (apparently some months old) being the characteristic accumulation of flotsam or drift lodged against shrubbery and elevations, and the equally characteristic gullies terminating in fans. The route lay almost directly across the slope, three to five miles from the base of the mountain; and the sheetflood-plain was so smooth that, with a little care in avoiding the occasional gullies, the wagon passed over it at a rapid trot, save in crossing a single sand-lined arroyo eight or ten feet deep and twenty yards across, the torrent marks indicating that the entire plain had been flooded for a width of nearly or quite ten miles to a depth exceeding a foot and not exceeding a yard, save in the central arroyo and one on either side (down which the drainage from the barrancas had evidently flowed streamwise after the force of the torrent was spent). This plain is a typical torrential apron of the Sonoran district; its slope, five miles from the mountain base, is perhaps 150 feet to the mile, increasing to 200 feet near the mountains and perhaps 300 in the reentrants between projecting spurs, while toward Rio Seco the inclination diminishes to 100 feet to the mile or less where the surface passes by a low crenulate escarpment into the broad wash of the pseudo-river, itself sloping probably 40 or 50 feet to the mile. The deposits of the plain as revealed in gullies and the marginal and central arroyos are gravelly and even bouldery sands near the mountain, grading into silty sands toward Rio Seco. These deposits have the customary air of great depth, yet, as shown in the walls of the barranca (the main head of Rio Seco) passing the frontier post of Sasabe and the lesser barranca near the Indian village of Poso Verde, they are usually but a yard or two in thickness for several miles from the mountains and rest on an eroded surface of non-decomposed mountain rocks.

Later the 1894 expedition passed up the broad valley extending northwestward from Hermosillo between two outlying ranges for about 100 miles. The greater part of this valley is a single torrential plain tilting up laterally into the bounding ranges and rising gradually northwestward from an altitude of perhaps 100 feet to over 2,000, where it seems to drown the mountains, save a few peaks rising sharply from its gentle surface; the regularity of the valley and its apparent lining being interrupted in four or five places by sharp-cut drainage-ways which have retrogressed through the westerly bounding range. About midlength of the valley (south of the tanque known as Agua Nueva) the route crossed obliquely the trail of a sheetflood, marked by flotsam and gullies, several miles broad. In this case the nearest upslope mountains were 20 or 30 miles away and not more than 2,500 feet higher than the flood-marks, while the surface inclined for 50 miles directly to the lower reach of Rio Sonora, which is never wet save by local showers or the storm freshets descending from the Sierra Madre during midwinter or midsummer rains. Accordingly it seemed clear that the sheetflood had been confined to the plain—that the waters of a single storm had accumulated, rushed down the 1:25 slope for ten or more miles, and then disappeared through absorption and evaporation.

During the exceptionally humid autumn of 1895, the second expedition experienced a single rain, or rather a succession of showers, not sufficient to produce either streams or sheetfloods, on the gentle slopes of Altar valley about the settlement and entrenched buttes of San Rafael de Alamito, where camp was pitched for several days. Yet this plain was marked for an area of at least 100 square miles by bunches of flotsam and driftwood lodged against the sparse shrubbery. The area was altogether out of reach of possible floods in Altar wash, to which, indeed, the marks did not extend, and the slope and direction of flow were nearly at right angles to its line. Except the geographically insignificant buttes, there were no mountains within a dozen miles in which the torrent might have gathered; and when the party ascended the 30-mile slope toward the Altar-Sonora divide the torrent-marks were found to diminish and gradually disappear in such manner as to demonstrate that the waters had gathered mainly, if not wholly, on the plain itself, and then rushed down toward, but apparently not quite to, the sand wash of the Altar. Where the flotsam was accumulated most abundantly the slope was probably 50 feet to the mile or less; and the fan-ended gullies were few and small, becoming more conspicuous further up the incline where the flotsam was less abundant.

The 1895 expedition skirted the western and southern bases of Sierra de Tonuco, just outside the area mapped as Seriland; and along the southwestern margin, near Rancho de Tonuco, the steep mountain side passed within a fraction of a mile into fairly smooth plain, sloping perhaps 150 feet to the mile. Numerous water-cut gullies and fans of exceptional size were found. Most of these were apparently some years old; and the deltas and fans contained quantities of angular and subangular boulders, sometimes reaching a foot in diameter. The deeper scorings here revealed a sheet of fragmental debris, evidently drift from the neighboring sierra, rarely reaching five feet in thickness, composed of little-worn gravel with occasional boulders embedded in a matrix of loam or silt; this rested on a sharply-eroded surface of granite or black marble not at all decomposed. The mantle was variable in thickness, averaging probably less than a yard over considerable areas, and frequently disappearing, leaving the rock to form the surface. About the rancho the alluvium thickened locally, and the ground water circulating on the subjacent rock surface was tapped by a well 40 or 50 feet deep; but even here, in the line of natural flowage from the deepest barranca of the sierra toward Encinas desert, where the slope was least, the usual gullies terminating in low fans abounded, some having been evidently produced by the latest storm. On the steeper slopes adjacent a number of low circular or elliptical mounds, apparently made up chiefly of angular boulders, were noted; and comparison of the evidently older with the manifestly young indicated that these were remnants of ancient gully-fans modified, rounded, and relatively raised above the mean surface by subsequent erosion, though in a few cases the boulder mounds were half buried by finer silt deposited about their flanks.

The 1894 expedition traversed Baboquivari or Moreno valley (west of Baboquivari range), crossing the course of "Fresnal creek" as shown on the excellent official map of Pima county, Arizona; and though the line of the "creek" was not traceable (the wash having been obliterated in consequence of local failure of rains during recent seasons), a considerable flotsam-marked area was found in the eastern part of the valley, below the Papago Indian villages collectively known as Fresnal. Here, too, in the shadow of the high and remarkably rugged granite range and its dominant peak, boulder mounds similar to those adjacent to Sierra de Tonuco were observed, and in two or three instances low buttes, together with the more considerable eminence known as Fresnal hill, were noted as apparently the product of continued circumdenudation, initiated about accumulations produced in the manner inferred in the Tonuco region. In this valley, too, it was observed that sometimes gullies of considerable dimensions are produced well out on the plain; in one instance the waters of a storm (apparently a local thunder-gust) had scooped out a basin 25 or 30 feet wide, 10 or 12 feet deep, and 250 feet long, then dammed its lower extremity with silty debris, and, finally, as the flow slackened, lined it with impervious silt which held water for months, and so located a Papago settlement; and cases were reported in which basins or tinajas of this character, refilled from season to season for some years, drew about themselves agricultural rancherias of Papago Indians, who built houses and planted fields around the banks in order that they might enjoy the priceless gift of their most potent deity.

In southwestern Arizona the sheetflood is well known to the Indians and to those Mexican and American rancheros who chance to be favorably situated, and they are well and expensively known to railway corporations, who sometimes have five miles or more of track washed out by a single storm perhaps sweeping over a smooth plain without a single waterway before, and with only a few new-made gullies after, the catastrophe. In essential features the local lay testimony is everywhere alike; there is a storm with exceptional precipitation, the water simply floods the surface in a muddy torrent or "wash" stretching as far as the eye can reach, the ground is swept of loose debris, and even of surface sands, while flotsam and sand heaps are piled up here and there; and in a few minutes, or perhaps a few hours in the lower valleys, the flood slackens and almost immediately disappears.

Such is the character of the sheetflood, as determined from direct observation, lay testimony, and the evidence of effects; and were it needful this evidence might be many times multiplied.

Conditions requisite for sheetflooding.—The main (perhaps the sole) source of the sheetflood is storm-water, comprising that shed from the mountains and that falling directly on the intermontane plains; and since the mountains are low and form only a small fraction of the surface, it seems clear that the chief source is the storm of the plains.

The first requisite for typical sheetflooding, then, is precipitation so rapid as to exceed immediate absorption by the dry earth and immediate evaporation in the drier air (for usually, in the Sonoran district, the precipitation horizon is some yards or hundreds of yards above ground, and the lower strata of the air are so hot and dry as to take up much of the falling and a part of the fallen moisture); and this involves several attendant conditions: One condition is that the temperature shall be high and the capacity for aqueous vapor great, in order that a large quantity of water may be produced when precipitation occurs; and this condition is amply met in the highly heated Sonoran district. An attendant condition is that the precipitation shall be rapid; and this also is met by the subtropical climate and wind-disturbing topography of the district. A third condition is that the soil shall be readily pervious only in limited degree or to limited depths; and this condition is met on the lightly veneered baselevels adjacent to the mountains, where the mantle only is porous and the under rocks sound and hard; it is not met in the deeper central portions of the valleys, where the permeable sands are of considerable depth. There are also other conditions which need not be noted in detail.

The second requisite is that there shall be abundant detritus, whereby the moving water may be readily loaded to the full limit of its capacity; and this requisite also involves several conditions: An important condition is absence of sward or turf to hold the earth-particles in union; this condition is fulfilled by the bare sands and naked rocks making up nine-tenths or more of the Sonoran surface. It is probable that another condition resides in chemical inertia of the mechanically comminuted rock-matter in the dry, coupled with some chemic activity promoting miscibility when wetted; and this condition is found in the friable sands and silts of the region, which form a tenaceous mud on saturation and a viscid slime on flooding. A third condition is dimensional heterogeneity in the debris, so that every part of the sheetflood may be loaded to its full capacity, whether its movement be swift or slow; and this condition is fully met on the upper plains, where silt, sand, gravel, and boulders in all sizes and shapes are intermingled, though it is less perfectly met in the valley interiors, where the materials are more completely assorted. Other conditions exist, but they are apparently of minor importance.

A third requisite is that the slope of the surface shall be of a certain somewhat variable value (not yet determinate save empirically as say 75 to 200 or possibly 300 feet per mile). The optimum or most efficient slope is evidently conditioned by thickness of the detritus mantle, which would appear to be considerable on the higher slopes, less on the lower slopes, and so great as to be an obstruction toward the valley interiors; by coarseness of the detritus, which always is greatest on the higher slopes; by dimensional heterogeneity, which in like manner culminates on the higher slopes; by porosity and friability, and by various other conditions. With slopes above the limit of efficiency, sheetflooding does not occur; the detritus is simply swept away, and the under-loaded storm-waters gather into streams, which carve channels. When the slope is below the limit of efficiency, the mechanism becomes clogged, the declivity and consequent velocity do not permit the incipient stream to overload itself quickly, and there is a tendency to assume the habit of streaming rather than that of sheetflooding. The various conditions of slope requisite for sheetflooding are strikingly met in the Sonoran district; two-fifths or more of its area consists of vast torrential aprons lightly veneered with detritus resting on baseleveled rocks, the inclination ranging between 75 and 250 feet per mile.

The final requisite for sheetflooding is that the volume of water, the mass of available debris for loading it, and the slope (and hence the velocity) shall be so interrelated and balanced that every part of the sheetflood may be loaded to its capacity, and that any temporary or sporadic increase in velocity may be quickly checked by overloading and consequent reduction of velocity. The conditions affecting this requisite are multifarious, probably beyond analysis, but it may be suggested that an important—perhaps the essential—condition is a progressive paralysis or weakening of the torrent due to the constant absorption and evaporation of its liquid element, the solid element remaining to burden immediately the falling or inflowing water. This condition is fully met in the parched air and burning sands of Papagueria.

On juxtaposing the requisite and qualifying conditions of sheetflooding, they are found in harmony with the distinctive characteristics of the greater part of the Sonoran district, and when the characteristics are compared with the conditions observed in special localities the harmony is rendered still more complete. It becomes evident that the sierras and buttes lie outside the domain of sheetflooding, since their slopes are too steep and their detritus too scanty; that the mountain-born streams on reaching the torrential plains must become quickly diverted and attenuated into sheetfloods, provided their volume be sufficient; that the light shower falling on the baselevel plain is absorbed, while the heavy shower must spread into a moving film and the cloud-burst into an irresistible sheetflood, sweeping all before it; and that the final feeble flow, whether from distant barrancas or local seepage in depressions, must resume the habit of the stream, pushing down toward the sea until the waters are finally lost.*

Erosive work of sheetfloods.—It may be affirmed from observation, both direct and indirect, and from necessary inferences concerning land-forms

* Reference is due to the work of Mr Willard D. Johnson during the second expedition, and to his opinions concerning the somewhat anomalous topographic features of the Sonoran district. Although sheetfloods were not witnessed during this expedition, Mr Johnson had opportunities for studying flotsam records, and in the course of his admirable topographic surveys he was much in contact with the features of the sand washes forming the fans or deltas of Rio Sonora, Rio Bacuache, and other principal drainageways. His conception of the Sonoran flood was commonly expressed by the term "interlacing drainage," consisting of a multitude of broad, shallow, and swift streams, approximately parallel in course, constantly divaricating and reuniting in such manner as to leave numerous islands, which were from time to time invaded and swept away. This conception is undoubtedly accurate so far as the lower reaches of the waterways are concerned, and it doubtless applies also to what the writer would consider as the lower or peripheral zone of sheetflooding proper, where there is a tendency toward the resumption of stream habit. Unfortunately Mr Johnson's observations and conclusions are not yet published; circumstances have prevented even the completion of his map, excepting the portion including Seriland; but important results may be anticipated.

and structure, that the sheetflood is an efficient agency (1) in transportation, (2) in corrasion, and incidentally (3) in deposition. Its efficiency is enhanced in the Sonoran district by various conditions, comprising all those essential to the existence of this form of water body, and including notably the local tendency toward the production of disintegrated and comminuted detritus rather than residua over the surface of mountain and plain—vegetation is too meager to produce appreciable quantities of humus acid, water is too scanty to aid materially in chemic action, frost is too rare and superficial and the included water too minute to rend the rocks effectually. Its efficiency is limited by the rarity of rainfall in sufficient quantity to produce flowage in any form—over the greater part of Papagueria, where the mean annual precipitation is probably no more than three to five inches, many tracts of 1,000 square miles or over are missed by the midwinter and midsummer storms of one or more years, the freshet-making storm may be three or five years in coming, and the great mantle-moving torrents are apparently separated by decades or centuries.

The efficiency of the sheetflood in transportation was amply shown by the relatively trivial torrent at Rancho de Bosque, which was literally a thin mortar of mud rather than water, and the well-preserved traces of sheetflood work in other localities gave unmistakable indications that great quantities of detritus were collected and transported. Inferences as to the behavior of greater sheetfloods rendered necessary by analogy and by the distinctive topographic configuration indicate with strong probability that the volume of material transported by the debacle increases in a higher ratio than the volume of water, so that the entire detrital mantle may be saturated to the point of mobility and carried down the slope in a sort of mud-flow peculiar only in its magnitude and in the dimensional heterogeneity of the moving particles.

The efficiency of the sheetflood in corrasion is made manifest by consideration of its mechanism: The velocity of flow must be considerable, else the flood is absorbed and evaporated; the water must be laden to its full capacity with abrasive material, else it runs clear and gathers into streams. This material, whether fine or coarse, is exceptionally hard and sharp rather than softened and rounded by decomposition, and the internal currents in the shallow sheet are such as constantly to batter and scour the subjacent surface as the mass half rolls and half slides across it. The inference from the character of the sheetflood is consonant with the necessary inference from the character of the baselevel surface. Over dozens or scores of square miles in carefully examined localities, hard rocks like those of the mountains, and with no sign of decomposition, are planed almost as smooth as the subsoil by the plowshare, with nothing either in configuration or in covering to indicate that streams have flowed over them, and extended consideration has yielded no other suggestion as to the eroding agent than that found also in analogy with the observed sheetflood. Moreover, these planed surfaces are not rare or exceptional; they occur under a definite law of distribution (with respect to sierras on the one hand and alluvium-lined valleys on the other) in all parts of the Sonoran region; their area may be estimated as two-fifths of the entire tract, or over 100,000 square miles. The efficiency of the sheetflood as a corrading agent is connected with its efficiency as an agent of transportation, for the rapid corrasion constantly furnishes material to be carried down the slopes, and this material in turn is available for cumulatively increasing the effective work of the agent.

The efficiency of the sheetflood in deposition would appear to be subordinate. In the miniature examples observed, a relatively considerable sheet of sediment was indeed laid down, yet it was no more than might be taken up and carried further down the slope by the next torrent, so that deposition in this case would seem to be little more than the mark of decadence; and in the various torrential plains on which the traces of past sheetfloods were found the conspicuous marks were those of degradation rather than aggradation. So far as the characteristics of the sheetflood are susceptible of analysis, too, it would seem that this form of flowage cannot maintain its distinctive attributes unless the detritus mantle is of limited thickness, so that deposition may be considered as essential and characteristic only to the extent of supplying abrasive materials for the next debacle within the sheetflood zone proper, while the external or peripheral deposition would appear rather to represent ordinary delta-building or stream-work. It is significant in this connection that many of the valley-plains (*e. g.*, San Luis valley, east of Baboquivira range) are much more strongly diversified by waterways and their attendant bluffs in their medial portions than half way up the gentle slopes toward the bounding mountains.

When the functions of sheetfloods are combined, it is found that their tendency is to recede or retrogress from the valley interiors, as these are progressively clogged with sediments, toward and into the bounding ranges; and this retrogressive cutting is one of the most significant features of the erosive process, partly in that it tends to produce anomalous profiles, passing abruptly from steep mountain side to nearly flat plain, in lieu of the gently sloping concave profile characteristic of stream-work. When the torrent filling the mountain barranca embouches on the plain, the first effect of the slackening in flow is the discharge of the detritus in a fan, which of itself tends to spread the water; and this fan protects the subjacent rock from corrasion. The slackened torrent may, indeed, divide on the fan surface into a number of streamlets divaricating over the contiguous part of the plain, but these are subject to the same law as the main stream and are continually divided and subdivided as they move down the diminishing incline; and thus the ultimate effect is to distribute the water widely and plane the fan into gentle curves, blending with the adjacent baselevel and sharply discordant with the mountain slope. As the process continues, the fan of one episode, particularly if produced by an exceeding torrent, may resist the powers of succeeding freshets, and thus initiate a butte in the line of the barranca, like Fresnal hill; and in some cases the salients between adjacent barrancas are cut through by the divergent floods in such manner as to form outlying buttes or cusps in line with the aretes ribbing the sierra, like some of the isolated buttes rising from the eastern apron of Sierra Seri, and the granite picacho with its half-mile pediment in the Seriland section near Puerta Infierno. The immediate consequence of this retrogression is the cumulative sharpening of the inflection in profile marking the base of the mountain; and it is noteworthy that the smaller mountain remnants on the flatter plains are (other things equal) steeper and more rugged than the greater mountain masses, as illustrated by Sierra de Tonuco and the little buttes in the northeastern part of Seriland in comparison with the high Sierra.

In brief, it may be affirmed, with so much confidence as the conditions of observation during two expeditions warrant, that the general effect of sheetflooding in the Sonoran district is to carve baselevel plains, lightly veneered by the carving material, about the medial altitudes; that these plains tend ever to retrogress into the mountains, and thereby steepen their slopes and render them exceptionally rugged; and that the anomalous topography of the region is not susceptible of explanation by other agencies.

It would be of interest to consider the natural history of sheetflooding in the region, and to obtain thereby a distinctive geomorphic record which might be compared with the stratigraphic record in reading the geologic history of the southwestern portion of the continent; but the time for this study has not yet come.

Sheetflood Work in other Districts.

While the requisite conditions for sheetflooding are especially favorable in the Sonoran district, and while the effects of the process are proportionately conspicuous, it is not to be supposed that the process is confined to the district—indeed it may be suggested that the process will be found a main or minor one in various districts, particularly those

BABOQUIVARI PEAK, LOOKING EASTWARD FROM FRESNAL

POSO VERDE PLAIN, LOOKING SOUTHEASTWARD

whose climate and configuration approach those of Papagueria. It may be noted as probable, also, that even in the more humid provinces a process analogous to that of sheetflooding may exist; for wheresoever rain falls the waters gather into a moving film before rivulets and streams are formed, and this film must be a more or less active geologic agent. Finally, it may be noted that certain obscure phenomena of various waterways which, like the Susquehanna and other Piedmont rivers in parts of their course, tend to corrade their channels laterally rather than vertically, appear to be akin to those of sheetflooding.

Explanation of Plates.

Plate 10.—*Baboquivari Peak, looking eastward from Fresnal.*

The summit of the peak rises about 4,500 feet above the plain in the foreground. So far as seen, the rocks of the range are ancient granites, passing into dark-colored schists near the western base. The conspicuous features of the sierra are steepness, ruggedness, and the dearth of taluses and foothills; the peak has never been climbed. The baselevel plain forming the foreground and middleground is exceptionally irregular, rising toward the right into a smaller counterpart of Fresnal hill (which is located directly in the rear of the point from which the photograph was taken). The surface deposit of the plain, as shown in the immediate foreground, consists of granitic debris in the form of angular boulders and pebbles, sharp sand, and silt; it usually ranges from two to five feet in thickness. The under-rocks of the plain, as shown in a deep arroya and its tributary gulches just beyond the field on the left, are dark schists and granitoid materials, similar to those forming the adjacent base of the sierra. The view illustrates the abrupt transition from mountain side to plain. The air-line distance to the nearest salient is about three miles and to the crest of the peak about five miles.

Plate 11.—*Poso Verde Plain, looking southeastward.*

The middleground represents part of the Papago Indian village of Poso Verde and, immediately beyond, the arroya forming the extension of a barranca heading in the mountains on the left. The central part of the picture shows the great torrential plain sloping southward to Rio Seco, on which sheetflood traces were found in 1894. The immediate foreground illustrates the usual relation between mountain-side and plain, the mountain rocks consisting of granite and the plain deposits of granitic debris. At this point the debris mantle is exceptionally thick (15 to 18 feet), as shown by the excavation about the spring supplying the village, but a few hundred yards down the slope toward the left granites are exposed within five feet of the surface of the plain, and the great arroya in the middleground bottoms on granite often rising nearly to the surface. The mountain spur forming the horizon left of the center is less rugged than usual, and its curved profile blending with that of the plain is exceptional—it is a nearly isolated mass affording little space for the gathering of waters, which are free to spread widely on approaching the plain. This salient is 7 or 8 miles, and the range faintly shown beyond 30 or 40 miles distant.

Plate 12.—*Coyote Mountain, looking eastward.*

Coyote mountain is an en echelon extension northward of Baboquivari range. The prevailing rocks are gray granites, with schists toward the base and on the adjacent plains. The altitude of the crest is probably about 5,500 feet, or 3,000 feet above the Indian village (Coyote) in the foreground. The conspicuous features, as at Fresnal, are steepness, ruggedness, and the small dimensions of taluses, fans, and foothills. The mountain face shown is practically inaccessible, and has never been climbed. Several low fans are shown, particularly at the right and somewhat left of the center; these have the form of alluvial accumulations, but actually consist of sharply carved mountain rocks, veneered thinly with granitic loam and gravel littered with great boulders. The plain in the foreground is thoroughly typical; the surface deposit is granitic debris, averaging less than a yard in thickness (so far as could be determined from several exposures), resting on the planed edges of rocks similar to those of the mountain. The view shows well the sharp transition from rugged mountain to smooth plain.

Plate 13.—*Torrential Aprons of Papagueria.*

The view represents the eastern side of the valley of Rio Magdalena, about twenty miles above Imuris. The mesquite-clothed foreground is alluvial, though underrocks crop out occasionally and appear in terraciform bluffs. The great aprons forming the background have the appearance of alluvial fans, such, e. g., as those described by Drew in northern India (Quarterly Journal of Geological Society, vol. xxix, 1873, p. 441, et seq.), yet analogy with all of the plains examined indicates that they are in greater part baseleveled mountain rocks thinly veneered with alluvial deposits. They were not visited. The sierra in the right background was somewhat doubtfully identified as belonging to the main Sierra Madre, in which case it is seventy-five or a hundred miles distant. Since the locality approaches the high Sierra, the slopes are steeper than those characteristic of the lower plains; the altitudes range from some 2,000 feet in the foreground valley to 3,500 in the aprons and 5,000 and upward in the nearer sierras.

COYOTE MOUNTAIN, LOOKING EASTWARD

TORRENTIAL APRONS OF PAPAGUERIA

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EARTH-CRUST MOVEMENTS AND THEIR CAUSES

ANNUAL ADDRESS BY THE PRESIDENT, JOSEPH LE CONTE

(*Read before the Society December 29, 1896*)

CONTENTS

INTRODUCTION.

SOURCES OF ENERGY.

Nearly all the processes of nature visible to us—well nigh the whole drama of nature enacted here on the surface of the earth—derive their forces from the sun. Currents of air and water in their eternally recurring cycles are a circulation driven by the sun. Plants derive their forces directly, and those of animals indirectly through plants, from it. All our machinery, whether wind-driven, or water-driven, or steam-driven, or electricity-driven, and even all the phenomena of intellectual, moral, and social activity, have still this same source. There is one, and but one, exception to this almost universal law, namely, that class of phenomena which geologists group under the general head of *igneous agencies*, comprising volcanoes, earthquakes, and more gradual movements of the earth's crust.

Thus, then, all geological agencies are primarily divided into two groups. In the one group come atmospheric, aqueous, and organic agencies, together with all other terrestrial phenomena which constitute the material of science; in the other group, igneous agencies and their phenomena alone. The forces in the one group are exterior; in the other, interior; in the one, sun-derived; in the other, earth-derived. The one forms, the other sculptures, the earth's features; the one rough-hews, the other shapes. The general effect of the one is to increase the inequalities of the earth's surface, the other to decrease and finally to destroy them. The configuration of the earth's surface, the distribution of land and water—in a word, all that constitutes physical geography at any geological time is determined by the state of balance between these two eternally antagonistic forces.

PHENOMENA TO BE STUDIED.

Now the phenomena of the first group, lying as they do on the surface and subject to direct observation, are comparatively well understood as to their laws and their causes. While the causes of the phenomena of the second group, hidden forever from direct observation in the inaccessible depths of the earth's interior, are still very obscure; and yet partly on account of this very obscurity, but mainly on account of their fundamental importance, it is just these which are the most fascinating to the geologist. The former group constituting, as it does, the terrestrial drama enacted by the sun, its interest is shared by geology equally with other departments of science, such as physics, chemistry, and biology. The phenomena of the second group are more distinctively the field of geology.

If we compare the earth with an organism, then these interior forces constitute its life-force, while the other group may be likened to the physical environments against which it eternally struggles, and the outcome of this struggle determines the course of the evolution of the whole. Now in biological science nearly the whole advance has heretofore been by study of the external and more easily understood phenomena, thus clearing the ground and gathering material for attack on the interior fortress, and the next great advance must be through better knowledge of the vital forces themselves. The same is true of geology. Nearly all the progress has heretofore been by the study of the exterior phenomena, such as erosion, transportation, sedimentation, stratification, distribution of organic forms in space and their succession in time, etcetera. Many of the laws of these phenomena have already been outlined, and progress today is mainly in filling in and completing this outline; but the next great step must be through a better knowledge of the interior forces. This is just what geological science is waiting for today. Now the first step in this direction is a clear statement of the problems to be solved. The object of this address is to contribute something, however small, to such clear statement.

EFFECTS OF INTERIOR FORCES.

As the interior of the earth is inaccessible to direct observation, we can reason concerning interior forces only by observation of their effects on the surface. Now these effects, as usually treated, are of three main kinds: (1) Volcanoes, including all eruptions of material from the interior; (2) Earthquakes, including all sensible movements, great and small; (3) Gradual, slow movements affecting large areas, imperceptible to the senses, but accumulating through indefinite time.

It is certain that of these three the last is by far the most fundamental and important, being, indeed, the cause of the other two. Volcanoes and earthquakes, although so striking and conspicuous, are probably but occasional accidents in the slow march of these grander movements. It is only of these last, therefore, that we shall now speak.

KINDS AND GRADES OF EARTH-CRUST MOVEMENTS.

The movements of the earth's crust determined by interior forces are of four orders of greatness: (1) Those greatest, most extensive, and probably primitive movements by which oceanic basins and continental masses were first differentiated and afterward developed to their present condition; (2) Those movements by lateral thrust by which mountain ranges were formed and continued to grow until balanced by exterior erosive forces; (3) Certain movements, often over large areas, but not continuous in one direction, and therefore not indefinitely cumulative like the two preceding, but oscillatory, first in one direction, then in another, now upward and then downward; (4) Movements by gravitative readjustment, determined by transfer of load from one place to another. Perhaps this last does not belong strictly to pure interior or earth-derived forces, since the transfer of load is probably always by exterior or sun-derived forces. Nevertheless they are so important as modifying the effects of other movements and have so important a bearing on the interior condition of the earth that they cannot be omitted in this connection.

Now of these four kinds and grades of movement the first two are primary and continuous in the same direction, and therefore cumulative, until balanced by leveling agencies. The other two, on the contrary, are not necessarily continuous in the same direction, but oscillatory. They are, moreover, secondary, and are imposed on the other two or primary movements as modifying, obscuring, and often even completely masking their effects. This important point will be brought out as we proceed. We will take up these movements successively in the order indicated above.

1. Ocean basin-making Movements.

I have already given my views on this most fundamental question very briefly in my "Elements of Geology," a little more fully in my first paper, "Origin of Earth Features,"* and in my memoir of Dana.† I give it still more fully now.

We may assume that the earth was at one time an incandescent, fused spheroid of much greater dimensions than now, and that it gradually cooled, solidified, and contracted to its present form, condition, and size. Now if at the time of its solidification it had been perfectly homogeneous in composition, in density, and in conductivity in every part, then the cooling and contraction would have been equal on every radius, and it would have retained its perfect, evenly spheroidal form; but such absolute homogeneity in all parts of so large a body would be in the last degree improbable. If, then, over some large areas the matter of the earth were denser and more conductive than over other large areas, the former areas, by reason of their greater density alone, would sink below the mean level and form hollows; for even in a solid—much more in a semi-liquid, as the earth was at that time—there must have been static equilibrium (*isostasy*) between such large areas. This would be the beginning of oceanic basins; but the inequalities from this cause alone would probably be very small but for the concurrence of another and much greater cause, viz, the greater conductivity of the same areas. Conductivity is not, indeed, strictly proportional to density; but in a general way it is so. It is certain, therefore, that the denser areas would be also the more conductive, and therefore the more rapidly cooling and contracting areas. This would again increase, and in this case progressively increase the depression of these areas. The two causes—density and conductivity, isostasy and contraction—would concur, but the latter would be far the greater, because indefinitely cumulative. The originally evenly spheroidal lithosphere would thus be deformed or distorted, and the distortion, fixed by solidification, would be continually increased until now. When the earth cooled sufficiently to precipitate atmospheric vapor the watery envelope thus formed would accumulate in the basins of the lithosphere and form the oceans. It is possible and even probable that

* Am. Jour. Sci., 1872.

† Bull. Geol. Soc. Am., vol. 7, 1895, pp. 461-474.

the depressions were at first so shallow that the primeval ocean may have been universal, but the process of greater downward contraction continuing, the ocean basins would become deeper and the less contracted portions of the lithosphere would appear as land. The process still continuing, the land would grow higher and more extensive and the ocean basins deeper and less extended throughout all geological time. On the whole, in spite of many oscillations, with increase and decrease of land, to be spoken of later, and in spite, too, of exterior agencies by erosion and sedimentation tending constantly to counteract these effects, such has been, I believe, the fact throughout all geological history.

It is evident, also, that on this view, since the same causes which originally formed the ocean basins have continued to operate in the same places, the positions of these greatest inequalities of the lithosphere have not substantially changed. This is the doctrine of the permanency of oceanic basins and continental masses, first announced by Dana. Some modification of this idea will come up under another head.

The objection which may be—which has been—raised against this view is that such heterogeneity as is here supposed, in a fused mass and therefore in a mass solidified from a state of fusion, is highly improbable, not to say impossible. This objection, I believe, will disappear when we remember the very small differences in conductivity, and therefore in contraction, that we are here dealing with; small, I mean, in comparison with the size of the earth. This is evident when we consider the inequalities of the earth's surface. The mean depth of the ocean is about two and one-half miles; the mean height of the land, about one-third of a mile. The mean inequality of the lithosphere, therefore, is less than three miles. This is $\frac{1}{1300}$ of the radius of the earth—less than $\frac{1}{100}$ of an inch (an almost imperceptible quantity) in a globe two feet in diameter. I believe that a perfectly spheroidal ball of plastic clay allowed to dry, or even a spheroidal ball of red-hot copper allowed to cool, would show more deformation by contraction than the lithosphere of the earth in its present condition. It is true the inequalities are more accentuated in some places, especially on the margins of the continental areas; but this is due to another cause, mountain-making, to be taken up later.

Another objection will doubtless occur to the thoughtful geologist. It would seem at first sight on this view that ocean areas cooling most rapidly ought to be the first to form a solid crust, and the crust (if there be any interior liquid still remaining) ought to be thickest, and therefore least subject to volcanic activity, there; but, on the contrary, we find that it is just in these areas that volcanoes are most abundant and active. It is for this reason that Dana believed that land areas were the first and ocean areas the last to crust over. This is probably true; but a little reflection will show that these two facts, namely, the earlier crusting of the land areas and the more rapid cooling and contraction of the ocean areas, are not inconsistent with one another; for the more conductive and rapidly cooling areas would really be the last to crust, because surface solidification would be delayed by the easy transference of heat from below, while the less conductive land areas would certainly be the first to crust, because the non-conductivity of these areas would prevent the access of heat from below. Observation of lavas proves this. The most vesicular and non-conductive lavas are the soonest to crust, but for that very reason the slowest to cool to great depths.

No doubt many other objections may be raised, especially if we attempt to carry out the idea into detail; for the physical principles involved, and especially the conditions under which they acted, are far too complex and imperfectly understood to admit of such detail. It is safest, therefore, to confine ourselves to the most general statement.

It may be well to stop a moment to compare with the above view that of Dana, as interpreted and clearly presented by Gilbert in 1893.* (1) According to this view, the earth is supposed to have first solidified at the center. This, on the whole, seems most probable. (2) The investing liquid, say from 50 to 100 miles thick, might well be supposed to arrange itself in layers of increasing density from the surface to the solid nucleus. Now suppose for any cause, less conductivity or other, certain areas crusted on the surface. These crusts would, of course, consist of the lighter superficial portions; but since rocks contract in the act of solidification,† these solidified crusts would sink to the nucleus and be replaced by similar lighter material flowing in from the surrounding surface, which in turn would solidify and sink. Thus would be built up from the nucleus below a solid mass consisting only of the superficial, lighter material to form the land, while the denser and less rapidly crusting material would form the ocean areas. As in my view, therefore, the oceanic areas are the denser and the land areas the lighter material.

It is evident that, according to either view, but especially according to mine, the material of the ocean basin areas down to the center of the earth must be as much denser than the material of the land areas down to the center as the subocean radii are shorter than the subcontinental radii, and therefore that the two areas must be in perfect static equilibrium with one another. Thus in the formation of continents the claims of isostasy are completely satisfied. I say completely because

* Bull. Geol. Soc. Am., vol. 4, 1893, p. 179.

† King and Barus. Am. Jour. Sci., vol. 45, 1893, p. 1.

this is not a partial equilibrium resisted by rigidity but enforced by pressure; it is original and without stress.

2. Mountain-making Movements.

I have so recently discussed this subject* that I shall have little more to say now. Mountain ranges are of two types, namely, the anticlinal or typical and the monoclinal or exceptional. The one are mountains of folded structure, determined by lateral thrust, the other of simpler structure and determined by unequal settling of great crust blocks. It is only of the former that I shall speak now. The other or monoclinal type will come up under another head.

It will not be questioned that mountain ranges of the first type are formed by lateral thrust, however much we may differ as to the cause of such thrust; nor will it be questioned that they are permanent features determined by continuous movement, however much they may be modified by other kinds of movement or reduced or even destroyed by subsequent erosion. I have placed them, therefore, among the effects of primary movements—that is, movements determined by causes affecting the whole earth. I have done so because until some more rational view shall be proposed I shall continue to hold that they are the effects of interior contraction concentrated upon certain lines of weakness of the crust and therefore of yielding to the lateral thrust thus generated. The reasons for, as well as the objections to, this view I have already on a previous occasion fully discussed. I wish now only to supplement what I have before said by some further criticisms of the most recent and, some think, the most potent objection to this contractional theory, namely, that derived from the supposed position of the "level of no strain."

It is admitted that the whole force of this objection is based on the extreme superficiality of this level, and that this in its turn depends on the initial temperature of the incandescent earth and the time elapsed since it began to cool. Both these are admitted to be very uncertain. I have already discussed these in my previous paper and shall not repeat here; but, as recently shown by Davison,† there are still other elements, entirely left out of account in previous calculations, which must greatly affect the result, and these new elements all concur to place the level of no strain much deeper than previous calculations would make it.

These neglected elements are the following: (1) The earth increases in temperature as we go down. Now the coefficient of contraction

* President's address, Am. Asso. Adv. Sci., Madison meeting, 1893.
† Am. Jour. Sci., vol. 47, 1894, p. 480. Phil. Mag., vol. 41, 1896, p. 133.

increases with temperature. This would increase the depth of the level of no strain and also, of course, the amount of interior contraction and therefore the lateral thrust. (2) The conductivity increases with the temperature. This also would increase the rate of cooling and therefore of interior contraction. (3) The interior of the earth is more conductive not only on account of its greater temperature, but also on account of its greater density; and this would be true whether the greater density be due to increased pressure or to difference of material, as, for example, to greater abundance of unoxidized metals. (4) The materials of the interior, aside from greater temperature and density, have a higher coefficient of contraction. (5) The usual calculations go on the assumption that the initial temperature was uniform for all depths. It probably increased with the depth then as now. This would again increase in an important degree both the depth of the level of no strain and the amount of lateral thrust.

The final result reached by Davison is, that while according to the usual calculations the level of no strain may be only a little over two miles (2.17) below the surface, yet taking into account only the first element mentioned above, the depth of that level would be increased to nearly eight miles (7.79), and taking into account all the elements it would come out many times greater still. The general conclusion arrived at is that the objections to the contractional theory, based on the depth of the level of no strain, must be regarded as invalid.

3. Oscillatory Movements.

The movements thus far considered are continuously progressive in one direction as long as they last. The resulting features are therefore permanent, except in so far as they may be modified by other movements or by degrading influences; but nothing is more certain than that besides these more steady movements there have been others of a more oscillatory character—that is, upward and downward—in the same place, affecting now smaller, now larger areas, and often many times repeated. These are the most common of all crust movements, and are shown everywhere and in all periods of the earth's history by unconformities of the stratified series. Every line of unconformity marks an old eroded land surface, and every conformable series of strata a sea bottom receiving sediments. We give but two striking examples of such oscillations.

The Colorado plateau was a sea bottom, continuously or nearly so, from the beginning of the Carboniferous to the end of the Cretaceous, and during that time received about 12,000 or 15,000 feet in thickness of sediments. During the whole of this time the area of the earth's crust was slowly sinking, and thus continually renewing the conditions of sedimentation. Why did it subside? At the end of the Cretaceous the same area began to rise. What change of conditions caused it now to rise? It has continued to rise until the present time, and is still rising. The whole amount of rise cannot be less than 20,000 feet; for if all the strata which has been removed by erosion were again restored, the highest portion of the arch which was sea bottom at the end of the Cretaceous would now be 20,000 feet high. This, however, is only the last oscillation of this area, for beneath the Carboniferous there are several unconformities showing several oscillations of the same kind in earlier periods. During the Devonian the area was land, for the Carboniferous rests unconformably on the Silurian. During the Silurian it was sea bottom, receiving sediments of that time. Beneath the Silurian there are two other unconformities showing similar oscillations. These earlier oscillations were probably as great as the one now going on, but we cannot measure them as we can the last.

Another striking example, still more recent and widespread, is the enormous oscillations of the Glacial period. It cannot be doubted that over very wide areas—several millions of square miles—there were at that time upward and downward movements of several thousand feet, and therefore producing enormous changes in physical geography and climate. What was the cause of these movements? They were doubtless modified, as will be shown later, by other movements superimposed on them; but the causes of the latter must not be confounded with that of the former.

We have given only two striking examples, but they are really the commonest of all crust movements. They are everywhere marked by unconformities of the strata; they are everywhere going on at the present time. In some places the sea is advancing on a subsiding land, in others a rising land is advancing on the sea. These movements are more conspicuous along coastlines, because the sea is a datum-level by which to measure them, but they affect equally the interior of continonts, as shown by the behavior of the rivers, which seek their base level by erosion in a rising and by sedimentation in a sinking country.

Many theories have been advanced to explain these movements, especially of certain very local shoreline movements. In volcanic regions they have been attributed to rise or recession of the volcanic heat and consequent columnar expansion or contraction of the crust. On non-volcanic sedimentary shorelines elevation has been attributed by some to the rise of the interior heat of the earth and consequent expansion of the crust produced by the blanketing effect of sedimentary deposit, while others with more reason think that regions of heavy sedimentation sink under the increasing load of accumulating sediments; but it is evident that, while such theories may explain some local examples in volcanic regions and along some shorelines, they cannot explain subsidences in the interior of continents, much less the wider and more extensive movements spoken of above. We must look for some more general cause. What is it?

It must be confessed that the cause of these oscillatory movements is the most inexplicable problem in geology. Not the slightest glimmer of light has yet been shed on it. I bring forward the problem here, not to solve it, for I confess my inability, but to differentiate it from other problems, and especially to draw attention to these movements as modifying the effects of movements of the first kind, and often so greatly modifying them as to obscure the principle of the permanency of oceanic basins and continental areas, and even to cause many to deny its truth. Nearly all the changes in physical geography in geological times, with their consequent changes in climate and in the character and distribution of organic forms—in fact, nearly all the details of the history of the earth—have been determined by these oscillatory movements; but amid all these oscillatory changes, sometimes of enormous amount and extent, it is believed that the places of the deep oceanic basins and of the continental masses, being determined by other and more primary causes, have remained substantially the same.

4. Movements by gravitative Readjustments—Isostasy.

This very important principle which, though partially recognized by Herschell, was first clearly enunciated by Major Dutton under the name isostasy.* The principle may be briefly stated thus: In so large a mass as the earth whether liquid within or solid throughout, it matters not excess or deficit of weight over large areas cannot exist permanently. The earth must gradually yield fluidally or plastically until static equilibrium is established or nearly so. Thus continuous transfer of material from one place to another by erosion and sedimentation must be attended with sinking of the crust in the loaded and rising of the crust in the unloaded area. In this way we may account for the sinking of the crust at the mouths of great rivers and the correlative rising of interior plateaus and nearly all great mountain regions observable at the present time. The same seems to have been true in all geological times, for it is obviously impossible that 40,000 feet of sediments could have accumulated

* Phil. Society of Washington, 1892.

in the Appalachian region in preparation for the Appalachian's birth unless there were continuous *pari passu* subsidence ever renewing the conditions of sedimentation.

Now there can be no doubt as to the value of this principle, but there is much doubt as to the extent of its application. The operation of exterior causes, such as transfer of load by erosion and sedimentation, are so comparatively simple and their effects so easily understood that we are tempted to push them beyond their legitimate domain, which in this case is to supplement and modify the more fundamental movements derived from interior causes. We are thus tempted to generalize too hastily and to conclude that all subsidence is due to weighting and all elevation to removal of weight. Probably this is a true cause, but not the main cause of such movements. Doubtless the proposition is true, but its converse is even much more so. It is certain that thick sediments may cause subsidence, but it is much more certain that subsidence, however determined, will cause continuous sedimentation by ever renewing the conditions of sedimentation. It is true that removal of weight by erosion will cause elevation, but it is more certain that elevation is the cause of removal of matter by erosion.

Take again the Plateau region as an example. We have seen that during the whole Carboniferous, Permian, Triassic, Jurassic, and Cretaceous times this region was subsiding, until at the end of the Cretaceous the earth's crust here had bent downward 12,000 or 15,000 feet. Shall we say it went down under the increasing load of sediments? Why, then, did it, from a previous land condition, ever commence to subside? And why, when the load was greatest, namely, at the end of the Cretaceous, did it begin to rise? Again, from that time to this it has risen 20,000 feet. Of this about 12,000 feet have been removed by erosion, leaving still 8,000 feet of elevation remaining. Now if this elevation be the result of removal of weight by erosion, how is it that a removal of 12,000 feet has caused an elevation of 20,000 feet? This result is natural enough, however, if elevation was the cause and erosion the effect, for the effect ought to lag behind the cause. It is evident, then, that we must look elsewhere—that is, in the interior of the earth—for the fundamental cause, although, indeed, the effects of this interior cause may be increased and continued by the addition and removal of weight.

But perhaps the best illustration of the distinctness of the two kinds of causes of these movements is found in the oscillations of the Quaternary period. I say best because in this case the effects of the two may be disentangled and viewed separately, and this in its turn is possible because the loading in this case is not by mere transfer from one place to another, and therefore is not correlated with unloading. In fact, the elevation in this case is associated with, and in spite of, loading. The elevation, as we all know, commenced in late Tertiary and culminated in early Glacial. This elevation was, at least, one cause, probably the main cause, of the cold and the ice accumulation, but the elevation continued in spite of the accumulating load of ice. Finally, however, the accumulating load prevailed over the elevating force and the previously rising area began to sink, but only because the interior elevatory forces had commenced to die out. Then with the sinking commenced a moderation of the climate, melting of the ice, removal of load, and consequent rising of the crust to the present condition, but far below the previous elevated condition, because the elevating forces, whatever these were, had in the meantime exhausted themselves. If it had not been for the interference of the ice-load, I suppose that instead of the double oscillation which actually occurred there would have been a simple curve of elevation coming down again to the present condition, but culminating a little later and rising a little higher than we actually find it did.

The question arises as to how great an area is necessary for the operation of the principle of isostasy? What extent and degree of inequality of surface may be upheld by earth rigidity alone?

The recent transcontinental gravitation-determinations by Putnam and their interpretation by Gilbert* seem to show a degree of rigidity greater than previously supposed. They seem to show that while the whole continental arch is certainly sustained by isostasy—that is, by deficiency of density below the sea level in that part, the continental area being lighter in proportion as it is higher—yet great mountain ranges like the Appalachian, Colorado, and Wasatch mountains show no such means of support, but are bodily upheld by earth rigidity; and even great plateaus like the Colorado plateau, 275 miles across, are largely, though not entirely, sustained in the same way.

Monoclinal Mountain Ranges.

Until recently mountain ranges were supposed to be all made in one way, namely, by lateral crushing and strata-folding and bulging along the line of yielding. To Gilbert is due the credit of having first drawn attention to another type, conspicuously represented only in the Plateau and Basin region, especially the latter—that is, those produced by tilting and irregular settling of the crust blocks between great fissures. The two types of mountains are completely contrasted in all respects. As to

* Gilbert: Phil. Soc. Washington, vol. 13, 1895, p. 31. Gilbert: Jour. Geology, vol. 3, 1895, p. 331. O. Fisher: Nature, vol. 52, 1895, p. 433.

form, the one is anticlinal, the other monoclinal. As to cause, the one is formed by lateral squeezing and strata-folding, the other by lateral stretching, fracturing, block-tilting, and unequal settling. As to place of birth, the one is born of marginal sea bottoms, the other is formed in the land crust. Classified by form, we may regard the two types as belonging to the same grade of earth features, namely, mountain ranges; but classified by their generating forces, they belong to entirely different groups of earth-movement. The one belongs to the second group mentioned above, the other to the third and fourth groups; for the plateau-lifting, crust-arching, and consequent tension and fracturing belong to the third group or oscillatory movements, but the mountain-making proper—that is, the subsequent block-tilting and unequal settling—belongs to the fourth group or isostasy, for that is wholly the result of isostatic readjustment and is one of the best illustrations of this principle. It shows on what comparatively small scale under favorable conditions (probably unstable foundation) the principle of isostasy may act.

It is evident, then, that it is impossible to exaggerate the distinction between these two types of mountains. They belong, as we have seen, to entirely different categories of interior forces, and, indeed, are not both mountains in the same sense at all. It was for this reason that in my paper on mountain structure* I put these latter in the category of mountain ridges instead of mountain ranges—of modification, not of formation. I now think it better to divide mountain ranges into two types, not forgetting, however, the very great distinction between them.

Conclusions.

To sum up, then, in a few words: There are two primary and permanent kinds of crust movements, namely, (*a*) those which give rise to those greatest inequalities of the earth surface—oceanic basins and continental surfaces; and (*b*) those which by interior contraction determine mountains of folded structure. These two are wholly determined by interior forces affecting the earth as a whole, the one by unequal radial contraction, the other by unequal concentric contraction—that is, contraction of the interior more than the exterior. There are also two secondary kinds of movement, which modify and often mask the effects of the other two and confuse our interpretation of them. These are (*c*) those oscillatory movements, often affecting large areas, which have been the commonest and most conspicuous of all movements in every geological period, and are, indeed, the only ones distinctly observable and

* Am. Jour. Sci., vol. 16, 1878, p. 95.

measurable at the present time, but for which no adequate cause has been assigned and no tenable theory proposed; and (*d*) isostatic movements or gravitative readjustments, by transfer of load from place to place, by erosion and sedimentation, or else loading and unloading by ice accumulation and removal, and also by readjustment of great crust blocks. If the previous one (*c*) or oscillatory movements have masked and so obscured the effects of (*a*) continent and ocean basin-making, this last (*d*), isostasy, has concealed the effects and obscured the interpretation of all the others, but especially of (*b* and *c*) mountain-making forces and the forces of oscillatory movements. In fact, in the minds of some recent writers it has well-nigh monopolized the whole field of crust movements. We shall not make secure progress until we keep these several kinds of movements and their causes distinct in our minds.

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STRATIGRAPHY AND PALEONTOLOGY OF THE LARAMIE AND RELATED FORMATIONS IN WYOMING*

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(*Read before the Society December 31, 1896*)

CONTENTS

INTRODUCTION.

Perhaps none of the various formations which contribute such important elements to the geologic history of the Rocky Mountain area have been the subject of so much discussion and difference of opinion as the series which has come recently to be known as the Laramie and allied formations. This series of strata, first known as the Lignite series, included the coal-bearing strata of the Upper Cretaceous with the lower Tertiary or Fort Union strata and was all regarded as Tertiary in age. Later the Laramie was differentiated by King as the uppermost division of the conformable Cretaceous series, and the Fort Union group ultimately associated

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with the lower Tertiary, although still regarded by some as belonging to the Laramie series. The Laramie as thus characterized was supposed to be very sharply circumscribed, but soon it was pointed out that certain of the lower coal-bearing members appeared to be in some cases included in the Fox Hills, or uppermost marine Cretaceous—that is, that there had been alternations of fresh and salt water conditions before the true Laramie age prevailed. As more detailed studies were made in Laramie areas it came to be evident that still further differentiation of the so-called Laramie was possible. In this way the Arapahoe and Denver formations have been removed and characterized by Messrs Eldridge and Cross in Colorado and the Livingston formation by Weed in Montana, and it appears possible in the light of investigations now in progress that even still further differentiation of the original Laramie will be found necessary.

As many of the supposed typical Laramie localities had been visited and studied by the various investigators some years ago, before the recognition of the Arapahoe, Denver, and Livingston formations, it became a matter of interest and importance to revisit these places and ascertain, if possible, the bearing of the new data on the questions of their distribution, life, etcetera. Other areas of later discovery, referred somewhat vaguely to the Laramie, had also been brought more or less in question, and the authors of this paper undertook an examination of various Laramie localities in Colorado, Wyoming, and Utah during the past season in hope that the two branches of paleontology represented might by being worked in conjunction lead to definite results.

As a preliminary to this study, we visited the type localities of the Arapahoe and Denver formations in the vicinity of Denver, Colorado, and familiarized ourselves with their stratigraphic and lithologic appearance. We also visited one of the well known localities for the supposed true Laramie on Crow creek in northeastern Colorado. We then studied in succession the Ceratops beds of Converse county, Wyoming, the Laramie plains (including the localities at Harper Station and vicinity, and Cooper and Dutton creeks), Carbon, Black Buttes, Point of Rocks, Rock Springs, Hams Fork, and Evanston in Wyoming, and Coalville, Utah.

Ceratops Beds of Converse County, Wyoming.

STRATIGRAPHY AND LOCAL DEVELOPMENT.

The stratigraphy of this region has been well described by Mr J. B. Hatcher,* whose sketch map showing the boundaries of the formation

*The Ceratops Beds of Converse County, Wyoming: Am. Jour. Sci., 3d ser., vol. xlv, pp. 135–144, February, 1893. Some Localities for Laramie Mammals and Horned Dinosaurs: Am. Naturalist, vol. xxx, pp. 112–120, February, 1896.

and the position of all important localities where he collected vertebrate fossils was of the greatest value to us. A part of Mr Hatcher's collection of invertebrates and plants having come into our hands, it was evident that important data might be obtained there for correlation with beds in other regions by means of these classes of organisms. With his map in hand it was an easy matter to locate our collections with reference to the vertebrates which have been obtained there.

The area examined by us extends along both sides of Lance creek from Little Lightning creek to Doegie creek, and from Buck creek on the east to about the mouth of Box creek on the west, the extreme distances being about 16 miles from north to south and 25 or 30 miles from east to west.

On the northern and eastern borders of this area the non-marine beds are sharply upturned and overlie with apparent conformity fossiliferous marine Cretaceous strata, of which several hundred feet are exposed where the streams have made favorable cuttings. The lowest beds exposed are the soft, bluish shales of the Fort Pierre, with frequent calcareous concretions containing characteristic invertebrates. Small collections from this horizon were obtained one mile east of Lance creek and on Buck creek near the old corrals, yielding the following species:

Avicula fibrosa, M. and H.
Inoceramus cripsii, Mantell.
Gervillia subtortuosa, M. and H.
Cucullæa shumardi, M. and H.
Protocardia subquadrata (E. and S.).
Dentalium gracile, H. and M.
Anchura sp.
Baculites ovatus, Say.
Scaphites nodosus (Owen).

The Fox Hills and the beds immediately overlying contain several massive sandstones, which together form a prominent ridge, usually bearing a few pine trees, and rising from 200 to 300 feet above the plain formed by the Fort Pierre shales. The succession and relations of the beds can be best shown by two local sections taken from the best exposures examined at localities about eight miles apart. The thicknesses were rather hastily estimated by pacing distances and measuring dips, but as the beds are very well exposed the errors are probably not great.

The first section is about two miles east of Lance creek, where the following strata were seen in ascending order:

1. Sandy clay shales, with occasional bands of brown sandstone; thickness unknown, as the base is not exposed.
2. Yellowish gray argillaceous sandstone, with large concretions containing *Veniella humilis*, *Sphæriola*, and other Fox Hills fossils, dip 20 degrees northwest, thickness........ 30 feet.
3. Brown micaceous sandstone........ 20 "
4. Gray thin-bedded sandstone........ 20 "

5. Brownish and gray sandstone, in alternating bands of, massive and thin-bedded	130	feet.
6. Massive light-colored sandstone	100	"
7. Clay	5	"
8. Sandstone	10	"
9. Clay	8	"
10. Massive light-colored sandstone	60	"
11. Lignite and clay	15	"
12. Shaly sandstone	5	"
13. Massive nearly white sandstone, with brown concretions	40	"
14. Clays with concretions containing *Ostrea glabra*, *Corbula subtrigonalis*, *Anomia*, and *Corbicula cytheriformis* (Laramie brackish-water fossils)	20	"
15. Similar clay with lignite seams	15	"
16. Sandstone with bands of clay	20	"
17. Clay	25	"
18. Sandstone	10	"

The beds to this point all have about the same dip of 20 degrees, and going up through the section northwestward the dips continue high, though gradually decreasing through similar alternating beds of clay and sandstone, with an aggregate of about 1,200 feet. This portion of the series was not found sufficiently well exposed to furnish a detailed section.

The second section, including the same horizons, is at the place described by Mr Hatcher,* in a gulch emptying into Buck creek near the old corrals used by cattlemen on their round-up. Here, as before, the Fort Pierre shales are fossiliferous, but very imperfectly exposed. The transition is gradual through alternations of sandstone and shales into the massive sandstones of the Fox Hills, with which the section begins.

1. Massive yellowish-gray friable sandstone, with concretions containing *Veniella humilis*, *Sphæriola*, *Gervillia subtortuosa*, and other Fox Hills fossils	100	feet.
2. Thin-bedded brown and gray shaly sandstone	130	"
3. Massive light-gray soft sandstone	60	"
4. Brown shaly sandstone	5	"
5. Soft, somewhat sandy, clay shales	30	"
6. Massive light-colored sandstone	75	"
7. Brown sandstone, more thinly bedded and somewhat more argillaceous than number 6	25	"
8. Yellowish massive sandstone, with large brown concretions	20	"
9. Massive light-colored sandstone like number 6	60	"
10. Sandy clays, with beds of lignite not well exposed; a few fossil plants were collected about this horizon a short distance from the line of the section	25	"
11. Alternating sandstones and clay shales in beds a few feet thick, not well exposed	275	"

* Am. Jour. Sci., 3d ser., vol. xlv, pp. 138, 139.

The total thickness of beds above the Fox Hills fossils to this horizon is 705 feet and the average dip is about 16 degrees northwest. The overlying beds, though not well exposed, appear to have the same steep dip in a belt nearly or quite a mile wide, so that the thickness of upturned beds above the Fox Hills fossiliferous zone is probably 1,500 to 2,000 feet.

On comparing these sections with Mr Hatcher's descriptions it is seen that the base of the Ceratops-bearing beds is above the massive sandstones, on about the same horizon as the brackish water Laramie fossils and the lowest bed from which plants were obtained.

The dip rapidly decreases to the west and northwest toward the middle of the basin, where the localities for the Ceratops vertebrate fauna are most numerous, and over the larger part of the area the beds are almost horizontal.

The accompanying sketch section (figure 1) shows the general structure and stratigraphy on a line extending northwesterly from the neighborhood of Buck creek to a point northwest of Lightning creek. The vertical scale and the dips are much exaggerated. The actual length of the section is 12 or 15 miles.

On the east side of Lance creek, nearly on the line of the first local section and not more than a mile north of the Fox Hills exposure, the dip is only 10 degrees. A few fossil plants were collected here, including *Menispermites* n. sp., and an *Equisetum* (?).

At a somewhat higher horizon, one and a half miles southeast of the U-L ranch, where the dip is scarcely perceptible, the following species of invertebrates were collected :

Anodonta parallela, White.
Sphærium sp.
Tulotoma thompsoni, White.
Campeloma multilineata, M. and H.
Campeloma producta, White (?)
Viviparus trochiformis, M. and H.
Physa copei, var. *canadensis*, Whiteaves.
Helix vetusta, M. and H.
Limnæa sp.

FIGURE 1.—*Section across the Converse County Area of Ceratops Beds.*

a, Fresh-water Miocene resting unconformably on Fort Pierre; *b*, Fox Hills; *c*, Base of Ceratops beds and horizon of brackish water Laramie fossils; *d*, Lance creek; *e*, Lightning creek; *f*, Horizon of Fort Union plants.

Associated with these there were a number of small bones, teeth, etcetera. This is noteworthy as the lowest horizon at which fresh-water invertebrates were found in this region.

The area underlain by the nearly horizontal Ceratops beds is an undulating grass-covered country, in which Lance creek, Lightning creek, and their tributaries have cut valleys 200 to 300 feet below the general level. Along their banks there are frequently nearly vertical cliffs 40 to 100 feet high, and the side gulches often exhibit typical bad lands erosion, so that there are numerous good exposures. The bedding is very irregular, however. sandstones passing horizontally into shales and *vice versa*, and it is difficult to fix exactly the relative positions of beds in different exposures. The very limited horizontal extent of some of the sandstones seems to have determined the topographic forms of the rounded hills capped by hard sandstone that are common on both sides of Lance creek.

Another peculiarity of the sandstones seen on Lance creek near the old U-L ranch and on the divide between Lance and Lightning creeks consists of very large indurated masses of sandstone, which, for want of a better name, we have called concretions, as Mr Hatcher also has done. Some of them are spherical, but the more common forms are elongated like irregular cylinders, often many feet in length, lying horizontally in the bed. More frequently the surface is smooth, but some specimens were seen quite regularly fluted. They are left scattered over the ground by the erosion of the softer enclosing sandstone and form very striking objects. They are probably not confined to a single bed, but the vertical range of the horizons in which we observed them is probably not more than 200 feet. They occur about 1,500 feet above the base of the Ceratops beds, not far from the horizon of the fossils last mentioned, and, according to Mr Hatcher, some of the specimens of *Triceratops* have been found in the concretions themselves. Professor J. E. Todd has observed and described* similar elongated masses in the Laramie near the head of Grand and Moreau rivers, South Dakota, some 200 miles north of the Lance Creek localities. He found there concretions arranged in longitudinal systems, and suggests that they mark the position of ancient beaches. Unfortunately we had not received Professor Todd's paper before going into the field, and the arrangement was not particularly noted; though it is our impression that no such regularity obtains where our observations were made.

Our largest collections of plants and invertebrates also came from this portion of the series. One of the best localities is in a bluff on the right bank of Lance creek just below the U-L ranch, where the following invertebrates were obtained :

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* Log-like concretions and fossil shores. Am. Geologist, vol. xvii, pp. 347–349, June, 1896.

Unio couesi, White.
Unio danæ, M. and H.
Unio holmesianus, White.
Unio brachyopisthus, White.
Sphæriam planum, M. and H.
Tulotoma thomsoni, White.
Campeloma multilineata, M. and H.
Goniobasis tenuicarinata, M. and H.
Thaumastus limnæiformis, M. and H. (?)

The collection also contained two undescribed species of Unio and a Sphærium that is probably new, besides the following species of plants from the same bed:

Myrica torreyi, Lx.
Viburnum whymperi, Heer.
Viburnum rotundifolium, Lx.
Aralia notata, Lx.
Aralia, 2 sp. nov.
Quercus, n. sp.

A clay bed at another locality on about the same horizon, one and a half miles southwest, yielded the following plants:

Alga (?).
Equisetum sp.
Asplenium, n. sp.
Salvinia, n. sp.
Cyperus sp.
Trapa (?) *microphylla*, Lx.
Castalia, 2 sp. nov.
Rhus (?), n. sp.

The following invertebrates were obtained in a sandstone immediately overlying the plant bed:

Unio danæ, M. and H.
Unio brachyopisthus, White.
Sphærium planum, M. and H.
Tulotoma thompsoni, White.
Campeloma multilineata, M. and H.
Physa copei, var. *canadensis*, Whiteaves.

The same fossils, with the addition of a few species, are found abundant at many places along Lance creek and on the divide between Lance and Lightning creeks, ranging through 300 or 400 feet of strata. On Lance creek, 4 miles north of U-L ranch, we collected:

Unio holmesianus, White.
Unio proavitus, White.
Unio sp.

Still farther north and two miles above the mouth of Lightning creek a bed on near the same horizon yielded a few plants:

Viburnum whymperi, Heer.
Quercus cinerioides, Lx.
Myrica, 2 sp. nov.
Salix sp.

together with:

Unio danæ, M. and H.
Unio brachyopisthus, White.
Unio (three undescribed species).
Sphærium sp.
Tulotoma thompsoni, White.

Near the top of the divide between Lance and Lightning creeks and opposite the last-mentioned locality there is a bed, composed of immense numbers of fresh-water shells, from which the following were collected :

Unio danæ, M. and H.
Unio brachyopisthus, White.
Unio holmesianus, White.
Unio (seven undescribed species, part of which are represented at other localities).
Sphærium sp.
Tulotoma thomsoni, White.
Campeloma multilineata, M. and H.

Again, on very near the same horizon as the last, on the north bank of Lightning creek, near its mouth, a small collection was made as follows :

Unio danæ, M. and H.
Anodonta parallela, White.
Campeloma multilineata, M. and H.
Campeloma producta, White.
Tulotoma thompsoni, White.
Physa copei, var. *canadensis*, Whiteaves.

The fossils of the above lists clearly all belong to one fresh-water fauna, which in this region has its greatest development in the upper 400 or 500 feet of the Ceratops beds. No fresh-water invertebrates have been found in the underlying several hundred feet of presumably fresh-water beds, and they are not abundant in those above the horizons above mentioned, but the few species that have been collected do not include any additional forms. On Lightning creek, a short distance west of the western limit of Ceratops beds, as given by Hatcher, and consequently overlying them, *Unio couesi*, White, occurs, and higher up in the same bluff *Campeloma multilineata*, M. and H., is abundant. Near the latter horizon a considerable collection of plants belonging to the Fort Union flora was obtained, including the following species :

Equisetum sp.
Anemia.
Sequoia nordenskioldi, Heer.
Sequoia, sp. (?)
Thuja, n. sp.
Salix sp.
Viburnum crenatum (?), Newberry
Viburnum, n. sp.
Viburnum, fruits of.
Cornus acuminata (?), Newberry.
Grewia celastrinoides, Ward.
Grewia crenata, (Ung.) Heer.
Celastrus curvinervis, Ward.
Celastrus pterospermoides, Ward.
Zizyphus serrulatus, Ward.
Zizyphus sp.
Vitis cuspidata, Ward.
Diospyrus brachysepala, Al. Br.

This list embraces 18 species, of which number at least 10 are species before described and which can be employed in determining the age. Nine of the 10 species are confined to the Fort Union group, the remaining species, *Diospyros brachysepala*, having a wide distribution, including Golden, Sand creek, and Sedalia, Colorado ; Black Buttes, Point of Rocks, Hodges pass, and Green river, Wyoming, and Fort Union, Montana. There seems, therefore, no doubt as to the correctness of referring this horizon to the Fort Union. This plant-bearing horizon is perhaps 300 or 400 feet above the Unio bed on the divide between Lance and Lightning creeks, and probably 100 to 200 feet above the highest beds from which Hatcher obtained Ceratops remains, as indicated on his map.* There is no apparent break in the stratigraphy, however, nor any decided change in the lithologic character of the beds other than an increase in the number of coal seams and in the proportion of clays, and the only reason for separating these overlying beds is the apparent absence of Ceratopsidæ from them and the change in the flora.

CORRELATION AS INDICATED BY THE INVERTEBRATE FAUNA.

The four species of brackish-water mollusks that were collected near the base of the series all occur elsewhere in the Laramie and are generally recognized as typical Laramie species, though very similar if not identical forms are found also in older Cretaceous beds. The fresh-water invertebrate fauna, occurring higher in the series, includes about 28 species, of which 18 are more or less confidently identified with described species, and the others are mostly new species of Unio.

Combining the lists of our local collections and adding a few species from Mr Hatcher's collections not obtained by us, the forms recognized are as follows:

†*Unio danæ*, M. and H.
†*Unio brachyopisthus*, White.
†*Unio couesi*, White.
†*Unio holmesianus*, White.
†*Unio proavitus*, White.
†*Unio endlichi*, White.
†*Unio cryptorhynchus*, White.
Unio (about eight undescribed species).
Anodonta parallela, White.
Anodonta propatoris, White (?)
Sphærium planum, M. and H.
Sphærium sp.
Viviparus trochiformis, M. and H.
†*Tulotoma thompsoni*, White.
Campeloma producta, White.
†*Campeloma multilineata*, M. and H.
Goniobasis tenuicarinata, M. and H.
Thaumastus limnæiformis, M. and H.
Physa copei, var. *canadensis*, Whiteaves.
Helix vetusta, M. and H.
Limnæa sp.

Of the 18 identified species in the above list, just half occur at Black Buttes, Wyoming, in or very near the bed that has yielded the saurian, *Agathaumas sylvestris*, Cope. The large proportion of identical forms and the general resemblance of the entire faunas, especially in the large number and great differentiation of species of Unio, makes it reasonably certain that the Converse county and Black Buttes beds are on nearly the same horizon. The evidence of the vertebrate fossils seems to tend in the

*American Naturalist, vol. xxx, February, 1896, pl. III.
†Species marked † occur at Black Buttes.

same direction. It will be shown later that the Black Buttes beds should be regarded as true Laramie, and consequently the series now under consideration is placed in the same category. Besides the nine Black Buttes species, there are seven additional that occur at other Laramie (including Judith River) localities. Five of the Converse county species were originally described from the Fort Union beds near the Yellowstone, and two of these are also known from the Eocene Wasatch.

EVIDENCE OF THE FLORA.

The plants found in these beds also afford evidence of considerable importance and interest. On combining the various species obtained within the area, together with several secured by Mr Hatcher, which we did not find, we have the following list of twenty-five forms:

Alga (determination uncertain).
Equisetum sp.
Asplenium, n. sp.
Salvinia, n. sp.
Cyperus sp.
Sabalites grayanus, Lx.
Palmocarpon commune, Lx.
Palmocarpon, n. sp.
Platanus raynoldsii, Newb.
Salix sp.
Quercus cinerioides, Lx.
Quercus sp.
Myrica torreyi, Lx.
Myrica, 2 sp. nov.
Trapa (?) *microphylla*, Lx.
Aralia notata, Lx.
Aralia, 2 sp. nov.
Viburnum whymperi, Heer.
Viburnum, n. sp.
Viburnum rotundifolium, Lx.
Castalea, 2 sp. nov.
Rhus, n. sp.

Four of the above-mentioned forms, *Sabalites grayanus*, *Palmocarpon commune* (?), *Palmocarpon* sp. nov., and *Platanus raynoldsii*, were collected by Mr Hatcher and not found by us. One of them (*Platanus raynoldsii*), represented by a large number of specimens, comes from just above the Ceratops beds, according to Hatcher. As this is a typical Fort Union plant, the horizon is undoubtedly near the one from which we obtained the rich Fort Union flora.

In case of the other forms obtained by Mr Hatcher, as they are labeled simply Converse county, we are unable to correlate them exactly with any of our localities. There is, however, no doubt about their being properly referred to this general section and included in this connection.

Of the remaining 24 forms it has been possible to identify satisfactorily only 8 species with forms before known, and one of these is from an unknown locality, thus having less than one-third of the total number on which to ascertain the bearing of the plants as to the question of age. Of the 7 remaining species, three are found at Black Buttes, in the vicinity of the Agathaumus bed, and one species (*Viburnum whymperi*) is confined to these beds, at least in this country. It is probably the most abundant form in Converse county. Forms, of which at least one is open to doubt, have been found at Point of Rocks in what has been supposed to be Laramie strata. One species is nearly confined to the Fort Union, showing that this flora had its beginning in the strata under consideration. Two of the above species have been found in the Laramie at Golden, Colorado, and one in the Raton mountains, New Mexico.

The affinity of the undescribed forms is also quite clearly with the true Laramie flora, and thus, as nearly as can be made out, the plants confirm the Laramie age of the Ceratops beds.

Coal-bearing Series of the Laramie Plains.

Coal beds have long been known to exist in the neighborhood of Rock creek and Cooper creek near the old stage road, 25 to 30 miles northwest of Laramie City, and they have been mined at intervals for local use for 30 years or more.* It has often been assumed that this coal is of Laramie age, though the geologists of the Fortieth Parallel Survey recognized its stratigraphic position beneath marine Cretaceous beds and referred it to the Fox hills. The importance and interesting nature of this series was called to our attention by Professor W. C. Knight, of the University of Wyoming, who generously gave us a week of his time and guided us to many important localities. One of the sections in which the relations of the different horizons are best exhibited is near Harpers Station, on the Union Pacific railroad, and within one or two miles of the original position of Miser Station, which is mentioned in some of the earlier geological reports. One mile northwest of Harpers there is an exposure of white sandstone with clays and coal seams, showing a total thickness of about 40 feet and dipping from 9 to 10 degrees south. Fossil plants are abundant near the base of the exposure and common in a band 20 to 25 feet higher, but the number of species represented is not large. They are interesting, however, from the fact that they are of certainly lower Laramie types or even older. The following is the list:

Sequoia reichenbachi (?), Gein.
Brachyphyllum, n. sp.
Anemia subcretacea, (Sap.) Gard. and Ett.
Cinnamomum affine, Lx.

The beds immediately overlying the coal-bearing series are usually covered, consisting apparently of soft clay shales. A fortunate exposure about 200 yards south of the plant-bearing locality, and consequently little more than 100 feet higher, shows a few feet of such clays with

* Hayden: Second Ann. Rep. U. S. Geol. Survey Terr., in reprint 1st, 2d, and 3d Reports, pp. 89, 90. Hague: U. S Geol. Expl. 40th Parallel, vol. ii, pp. 86, 87. King: Ibidem, vol. i, p. 321.

harder bands and concretions that have yielded the following characteristic Cretaceous species:

Chlamys nebrascensis, M. and H.
Inoceramus cripsii var. *barabini*, Morton.
Baculites ovatus, Say.

These species occur in both the Fort Pierre and Fox Hills beds, which are not very clearly differentiated in this region, but the fauna of the underlying beds shows that we are here probably in the Fox Hills beds. Since our return from the field Professor Knight informs us that he has found a Fox Hills fauna fully a mile farther south and probably 1,000 feet higher than the plant-bearing horizon.

This same coal and plant horizon is exposed on the west side of the railroad extending westward several miles toward Rock creek from a point about one mile west of Harpers. The light-colored sandstones associated with the coal are here exposed to a thickness of about 75 feet, dipping 17 degrees south, and forming a prominent line of cliffs. In the upper part of the exposure, at a locality about five miles west of Harpers, a few fossil plants were collected, including *Sequoia reichenbachii* (?) Gein, and *Cinnamomum affine*, Lx.

The stratigraphic relation of the plant bed to the overlying marine strata was again confirmed by finding a fossiliferous horizon in brown and gray sandstone from 500 to 600 feet above the plant zone and apparently conformable with it. The following Montana species were obtained here:

Cstrea sp.
Avicula nebrascana, E. and S.
Baculites ovatus, Say.
Baculites compressus, Say.
Scaphites sp.

The beds below the coal horizon probably belong to the upper part of the Fort Pierre, but on the Laramie plains, as in many other regions, no sharp distinction, either paleontologic or lithologic, can be drawn between the Fort Pierre and the Fox Hills, and it is usually more convenient as well as safer to speak of them collectively as the Montana formation. These lower beds contain several fossiliferous horizons, two of which are especially prominent, both on account of the number and variety of their fossils and from the fact that they are in hard sandstones, whose outcrops form narrow ridges that can be traced continuously for several miles on both sides of the railroad near Harpers. Collections were made from the upper of these horizons, which is from 400 to 500 feet below the coal, at several localities within the limits just indicated. The list of species is as follows:

Ostrea inornata, M. and H.
Ostrea plumosa, Morton.
Syncylonema rigida, (H. and M.)
Avicula linguæformis, E. and S.
Inoceramus cripsii, var. *barabini*, Morton.
Inoceramus sagensis, Owen.
Inoceramus sagensis, Owen, variety.
Inoceramus, n. sp.
Modiola meeki, (E. and S.)
Pinna lakesi, White.
Limopsis parvula, M. and H.
Eriphyla gregaria, M. and H.
Liopistha (*Cymella*) *undata*, M. and H.
Dentalium gracile, H. and M.
Margarita nebrascensis, M. and H.
Lunatia occidentalis, M. and H.
Anchura rostrata, (Gabb.)
Cerithiopsis moreauensis, M. and H.
Fasciolaria (*Piestochilus*) *alleni*, White.
Fusus (*Serrifusus*) *dakotensis*, M. and H. var.
Baculites ovatus, Say.
Placenticeras placenta, (Dekay.)
Placenticeras placenta, var. *intercalare*, M. and H.
Ptychoceras mortoni, M. and H. (?)
Ptychoceras crassum, Whitfield.
Heteroceras angulatum, M. and H. (?)
Heteroceras nebrascense, M. and H.
Heteroceras cochleatum, M. and H.
Emperoceras beecheri, Hyatt (?)
Helicoceras mortoni, var. *tenuicostatum*, M. and H.
Scaphites nodosus, var. *brevis*, Meek.

The other fossiliferous horizon which is 300 or 400 feet lower, yields many of the same species, together with a few others that seem to be peculiar to it, as will be seen by the following list:

Ostrea pellucida, M. and H.
Ostrea inornata, M. and H.
Anomia sp.
Syncyclonema rigida, (H. and M.)
Camptonectes cf. parvus, Whitfield.
Avicula linguæformis, E. and S.
Avicula nebrascana, E. and S.
Gervillia sp.
Inoceramus cripsii, var. *barabini*, Morton.
Inoceramus sagensis, var. *nebrascensis*, Owen.
Inoceramus pertenuis, M. and H.
Modiola alternata, M. and H.
Pinna lakesi, White.
Yoldia evansana, M. and H.
Trigonia, n. sp.
Caprinella coralloidea, H. and M.
Protocardia subquadrata, (E. and S.)
Cardium speciosum, M. and H.
Legumen planulatum, Conrad.
Tellina scitula, M. and H.
Glycimeris berthoudi, White.
Anatina sp.
Liopistha (*Cymella*) *undata*, M. and H.
Mactra sp.
Dentalium gracile, H. and M.
Lunatia occidentalis, M. and H.
Vanikoro ambigua, M. and H.
Margarita nebrascensis, M. and H.
Anchura americana, (E. and S.)
Anchura rostrata, (Gabb.)
Aporrhais meeki, Whitf. (?)
Fusus (*Serrifusus*) *dakotensis*, M. and H.
Pyrifusus newberryi, M. and H. (?)
Fasciolaria (*Mesorhytis*) *gracilenta*, M. and H. (?)
Anisomyon borealis, M. and H.
Anisomyon patelliformis, M. and H.
Cylichna sp.
Actæon sp.
Pachydiscus complexus, (H. and M.)
Placenticeras placenta, var. *intercalare*, M. and H.
Baculites ovatus, Say.
Ptychoceras crassum, Whitf.
Heteroceras sp.
Helicoceras mortoni, var. *tenuicostatum*, M. and H.

The species of these lists are nearly all of common occurrence in the

Montana formation of the Rocky Mountain region, but a few of them are worthy of special notice. *Pachydiscus complexus* (H. and M.), which has hitherto been known from a few immature specimens, is here not rare, and attains a diameter of six or eight inches.* At least two other species not hitherto reported from the northwest, *Legumen planulatum* and *Anchura rostrata*, are common in the Ripley beds of Alabama, Mississippi, and Texas, and the undescribed *Trigonia* is closely related to *T. eufalensis*, also from the Ripley. The *Legumen* is apparently congeneric with Meek's *Baroda wyomingensis*. New collections are thus gradually increasing the number of forms common to the Ripley and Montana formations, although the specific differences between these two presumably contemporaneous faunas are still so numerous that we must assume either considerable climatic differences or partial isolation of the two areas of deposition.

Fossil plants were obtained on the Laramie plains at three other localities where the stratigraphic position is not so plainly evident as at the localities already mentioned. One of these is near Dunn's ranch on Laramie river, six miles east of Harpers, where the following species were collected:

Myrica torreyi, Lx.
Quercus acrodon, Lx.
Ficus planicostata, Lx.
Celastrus, n. sp.
Salix sp.
Spathites sp.

It is almost certain that this locality is very near the coal and plant bearing horizon already discussed, yet none of the plants are common to the two localities.

Near the old stage road on the north fork of Dutton creek, between Rock and Cooper creeks, there is a small coal bed that has been mined to some extent for local use. It is probably the one spoken of as the "Cooper Creek Coal" in the reports cited on page 137. The shale overlying the coal and the still higher sandstone both contain fossil plants, among which the following, mostly from the shale, were recognized:

Aspidium, n. sp.
Asplenium, n. sp.
Woodwardia, n. sp.
Brachyphyllum, n. sp.
Sequoia reichenbachi, Gein.
Trapa (?) *microphylla*, Lx.
Ficus sp.
Castalia, n. sp.
Asimina eocenica, Lx.
Diospyros (?) *ficoidea*, Lx.

The evidence afforded by these plants, while somewhat conflicting, tends to place this horizon quite low down in the series, or approximately similar to the plant horizon at Harpers Station. Two of the species

* Large specimens of this species have been reported from Texas by Cragin.

(*Brachyphyllum*, n. sp., and *Sequoia reichenbachi*) are found at Harpers Station and two other of the named species (*Trapa* (?) *microphylla* and *Diospyrus* (?) *ficoidea*) are found at Black Buttes and Point of Rocks. The latter species are also found in the Fort Union beds, but in the lower horizon. The other named species (*Asimina eocenica*), depending on a single example, has been found in the Denver beds at Golden, Colorado, and at Carbon, Wyoming. The unnamed species, as far as they have affinities, appear to approach more closely to those of the so-called true Laramie.

The associated strata are not exposed in the immediate neighborhood, but about three miles to the southwest, near the old stage road crossing Cooper creek, beds that are certainly higher in position are very fossiliferous, yielding a characteristic Fox Hills fauna as follows:

Micrabacia americana, M. and H.
Ostrea sp.
Anomia sp.
Inoceramus cripsii, var. *barabini*, Morton.
Inoceramus sagensis, var. *nebrascensis*, Owen.
Avicula linguæformis, E. and S.
Avicula nebrascana, E. and S.
Gervillia sp.
Modiola galpiniana, (E. and S.)
Pectunculus wyomingensis, (Meek).
Protocardia subquadrata, (E. and S.)
Syncyclonema rigida, (H. and M.)
Lucina subundata, H. and M.
Crassatellina sp.
Tancredia americana, M. and H.
Callista (*Dosiniopsis*) *nebrascensis*, M. and H.
Tellina scitula, M. and H.
Goniomya americana, M. and H.
Corbulamella gregaria, M. and H.
Martesia sp.
Lunatia concinna, (H. and M.)
Capulus sp.
Nautilus dekayi, Morton.
Baculites ovatus, Say.
Scaphites nodosus, (Owen.)

The third of the plant localities above referred to is six or seven miles northeast of the coal opening last mentioned. It is at a coal mine now known as the "Dutton Creek" mine, although it is not on Dutton creek, but in a ravine leading down to Rock creek, and it may be the Rock Creek coal of the earlier reports. The exposures in the neighborhood are small, and we were unable to determine its stratigraphic relations with any of the other coal beds examined or with any established horizon. The evidence of the fossil plants, which are abundant in the shales and sandstones immediately above the coal, is in favor of correlating the coal with that at Carbon and assigning it to a higher horizon than the other coal beds of the Laramie plains. The following species were collected:

Anemia.
Glyptostrobus ungeri (?).
Salix media (?).
Populus arctica, Heer.
Ficus uncata, Lx.
Ficus, 2 sp. nov.
Ficus pseudo-populus, Lx.
Juglans rugosa, Lx.

Populus knightii, n. sp.* Kn.
Quercus platania, Heer.
Alnus keeferstenii, (Göpp) Ung.
Corylus macquarryi, (Foobes) Heer.
Trapa, n. sp.
Betula stevensoni, Lx.
Platanus sp.
Grewiopsis saportanea, Lx.
Asimina eocenica, Lx.
Sapindus, n. sp.
Cissus tricuspidata, Lx.
Fraxinus sp.
Magnolia tenuirachis, Lx.

Of the 15 species identified with previously known forms, no less than 7 are found at Carbon, often in great abundance, and 3 of these are known from no other place. Several of the remaining species are reported from Evanston or in higher beds. There can be little doubt as to their affinities with Carbon, and we therefore refer these beds provisionally to this horizon.

It is evident from the preceding notes that the coal-bearing series of the Laramie plains is in large part, if not wholly, older than the true Laramie, as that formation is usually defined, although it yields what has been supposed to be a Laramie flora ; that is, instead of conformably overlying the Fox Hills beds, it is overlain by them or included within them. Such an occurrence is, however, by no means exceptional in the Cretaceous of the northwest. The Belly River series of the Canadian geologists is a coal-bearing formation holding a similar, but perhaps somewhat lower, position in the Cretaceous section. It also has a freshwater fauna, and a flora consisting mostly of Laramie species. The principal coal bed, near the mouth of Judith river, Montana, is several hundred feet below the top of the Fox Hills beds, and from another Montana locality north of the Musselshell river, Mr Lindgren † has reported several marine Cretaceous species from a bed overlying coal that he referred to the Laramie. Mr R. C. Hills ‡ has found marine Cretaceous fossils above "Laramie" coal beds, with a so-called Laramie flora in western Colorado, and one of the present writers § has collected about a dozen species of plants, including several Laramie species, from a bed at Coalville, Utah, that is overlain by about 1,800 feet of marine Cretaceous beds. The Fox Hills beds are coal-bearing at Durango, and in the Mesa Verde, in southwestern Colorado, and will doubtless yield a flora of land plants, though no identified species have been recorded from them. During the past season we have also found that the well-known plant

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*Similar to *P. arctica*, but differing in being generally smaller and in having prominent, obtuse teeth, amounting almost to lobes. It is named in honor of Professor W. C. Knight, who did so much to facilitate our investigations.

† Tenth Census Report, vol. xv, Mining Industries, p. 744.

‡ Proc. Colorado Scientific Society, vol. iii, part 3, 1890, p. 381.

§ Bull. U. S. Geol. Survey, no. 106, p. 42.

horizon at Point of Rocks, Wyoming, holds a similar position beneath marine beds, as we shall show more in detail.

Localities in Bitter Creek Valley.

BLACK BUTTES.

The stratigraphy and paleontology of Bitter Creek valley have been discussed and described more frequently and by a greater number of authors* than any other similar area that has been referred to the Laramie. Besides being easily accessible and within the areas studied by three of the geological survey organizations that were working in the west 20 years ago, it became important on account of the abundant and varied paleontological material it afforded. The first Dinosaur (*Agathaumas sylvestris*) recognized in the Laramie was found at Black Buttes. The same locality has yielded a large number of fossil plants and a greater proportion of the described invertebrate species of the Laramie than any other single locality. The other places along Bitter creek mentioned beyond have also yielded plant and invertebrate fossils, and important coal beds have been more or less developed at all three localities.

The most prominent feature of the section at Black Buttes is the massive bed of sandstone, somewhat over 100 feet thick at the base of the exposure, forming steep hills and cliffs northeast of the railroad opposite the station and passing beneath the surface by its dip of 9 or 10 degrees near the coal mine. The upper portion of it is also exposed on the south side of Bitter Creek valley, about a mile from the station. All of the Laramie fossils, whether plants, invertebrates, or vertebrates, that have hitherto been described or listed as coming from Black Buttes were obtained from the overlying beds within about 100 feet of the top of this massive sandstone. The original specimen of *Agathaumas sylvestris* was found about 20 feet above it, and the plants that have been described came from the same horizon and from several higher bands up to the bed overlying the principal coal, some 60 or 75 feet higher. The invertebrates from this locality have about the same range. Most of the beds vary considerably

* Hayden: Reprint of 1st, 2d, and 3d Ann. Reports U. S. Geol. Survey Terr., pp. 99–100; Bull. U. S. Geol. Survey Terr., vol. i, pp. 401–411, 1876. Cope: Proc. Am. Philos. Soc., vol. xii, 1872, pp. 481–483; Am. Naturalist, vol. vi, 1872, pp. 669–671; Ann. Rep. U. S. Geol. Survey Terr. for 1873, pp. 435, 436; Bull. U. S. Geol. Survey Terr., 1st ser., no. 2, pp. 5–13. Meek: Ann. Rep. U. S. Geol. Survey Terr. for 1872, pp. 455–456; U. S. Geol. Survey Terr., 4°, vol. ix, pp. li–lv, 1876. Bannister: Ann. Rep. U. S. Geol. Survey Terr. for 1872, pp. 526, 527, 535. Lesquereux: Idem for 1873, p. 373; Idem for 1874, p. 285; Bull. U. S. Geol. Survey Terr., vol. i, 1876, pp. 233–248, 363–382; The Tertiary Flora, 1878, pp. 25–31, 342–344, 347–352. Powell: Geology of the Uinta Mountains, pp. 45–49, 162–166, 1876. Emmons: U. S. Geol. Expl. 40th Parallel, vol. ii, 1877, pp. 227–236. King: Idem, vol. i, 1878, pp. 331–337. White: Bull. U. S. Geol. Survey Terr., vol. iii, 1877, pp. 599–616; Ann. Rep. U. S. Geol. Survey Terr. for 1877, pp. 215–224; Idem for 1878, pp. 49–103. Ward: 6th Ann. Rep. U. S. Geol. Survey, 1886, pp. 539, 540.

in character and thickness within short distances, but the fossiliferous and overlying portions of the section may be described in general terms as a series of variable sandstones, clays, and coal beds exposed in low hills and ridges with a dip of 9 or 10 degrees eastward at the base, but decreasing in the upper portions to 5 or 6 degrees, which is about the same as the dip of the overlying Wasatch beds.

The character of the mollusks shows that the lower beds were mostly deposited in brackish waters, but that there were alterations of fresh waters in which the genus *Unio* thrived with an abundance of individuals and great variety of species, and several fresh-water gasteropods were common. Between the top of the massive sandstone and the Dinosaur horizon there is a band filled with brackish-water fossils, including *Ostrea glabra*, var. *arcuatilis*, Meek; *Anomia micronema*, Meek; *Corbula undifera*, Meek, and *Modiola* sp. The greater number of the Black Buttes invertebrates, however, have been obtained from strata some 40 or 50 feet higher, and consequently a little above the Dinosaur bed. Here there is a band which in some places is about four feet thick, almost wholly made up of shells. By far the most abundant species is *Corbicula fracta*, Meek, and immediately associated with it are *Corbicula occidentalis*, M. and H.; *Neritina baptista*, White; *N. volvilineata*, White, and *Melania wyomingensis*, Meek, all of which probably lived in slightly brackish water, for this species of *Melania* has almost invariably been found associated with brackish water or marine forms, although it belongs to a fresh-water genus. At the base of this shell bed and immediately above a coal seam *Unio* shells are abundant. These purely fresh-water forms are found on the slope mingled with the *Corbicula* shells, but all that were found *in situ* were either at the base of or a few feet above the *Corbicula* bed.

The Unione fauna is strikingly like that of the Ceratops beds in Converse county, as the following list of species will show:

Unio couesi, White.
Unio propheticus, White.
Unio aldrichi, White.
Unio proavitus, White.
Unio holmesianus, White.
Unio endlichi, White.
Unio cryptorhynchus, White.
Unio brachyopisthus, White.
Unio goniambonatus, White.
Unio danæ, M. and H.

Immediately above the *Corbicula* bed a band is locally filled with *Tulotoma thompsoni* and occasional *Unios*, and it is overlain by shales containing *Ostrea* and *Anomia* in the lower part and the following species above:

Unio couesi, White.
Corbula undifera, Meek.
Corbula subtrigonalis, M. and H.
Cassiopella turricula, White.
Goniobasis gracilenta, M. and H. (?)
Viviparus plicapressus, White.
Campeloma vetula, M. and H.
Campeloma multilineata, M. and H.

The fossil plants of Black Buttes, ranging through the same strata as the invertebrates and extending up a few feet higher to the bed just above the principal coal, are as follows:

Apeibopsis discolor, Lx.
Cissites lobato-crenata, Lx.
Cissites tricuspidata, Heer.
Ficus planicostata, Lx.
Ficus planicostata latifolia, Lx.
Grewiopsis saportanea, Lx.
Grewiopsis tenuifolia, Lx.
Myrica torreyi, Lx.
Ophegrapha antiqua, Lx.
Pisonia racemosa, Lx.
Podogonium americanum, Lx.
Quercus viburnifolia, Lx.
Rhamnus salicifolius, Lx.
Sapindus caudatus, Lx.
Sequoia acuminata, Lx.
Smilax grandifolia, Ung.
Viburnum marginatum, Lx.
Viburnum platanoides, Lx.
Viburnum rotundifolium, Lx.
Viburnum whymperi, Heer.
Zizyphus fibrillosus, Lx.

The higher beds of the section are lithologically very much like these fossiliferous coal-bearing strata near the base. They are exposed in the valley of Bitter creek for several miles east and southeast of Black Buttes before the recognized Eocene is reached. A careful estimate, based on the dips and distance across the strike, gives a total thickness of about 2,000 feet above the basal sandstone. No identifiable animal remains were found within this series above the horizon already discussed, but plants were collected from three other horizons associated with thin coal beds. One of these, which is at least 700 or 800 feet above the *Corbicula* bed, contains well preserved plants in great numbers, though only a few species are represented. Their affinities are closest with the Fort Union flora, as may be seen from the following list of species, all of which are confined to or found abundantly in the Fort Union:

Glyptostrobus ungeri, Heer.
Quercus dentoni, Lx.
Sapindus obtusifolius, Lx.
Conus fosteri, Ward.
Tetranthera præcursoria, Lx.
New species belonging to the genera *Anemia*, *Cyperacites*, *Ficus*, *Rhus*, *Magnolia*, *Juglans*, *Cinnamomum*, etcetera.

The other two horizons are near each other, several hundred feet higher, and not more than a couple of hundred feet below the apparent base of the Wasatch. The plants, which seemed similar to those of the last list, were unfortunately lost in transit.

Still higher in the section, at a point about eight miles southeast of Black Buttes, there are two calcareous beds, separated by 50 feet of strata, both of which contain numerous specimens of *Physa pleromatis*, White, with *Planorbis militaris*, White; *Helix* (?) sp., *Viviparus wyomingensis*, Meek, and fragmentary remains of turtles. Similar beds bearing the same invertebrate fossils occur near the base of the Wasatch in the neighborhood of Castle Gate and Pleasant Valley junction, Utah, where the Wasatch seems to be conformable on the Laramie, without intervening beds. Another very fossiliferous bed, some 400 feet higher, yielded the following characteristic Eocene mollusks:

Unio shoshonensis, White.
Unio washakiensis, Meek.
Goniobasis tenera (Hall).
Viviparus paludinæformis, Hall.

This section beneath the Fort Union plants has a close general resemblance to that of the Ceratops beds in Converse county, and the paleontological evidence is in favor of correlating them.

POINT OF ROCKS.

At Point of Rocks, 11 miles northwest of Black Buttes, a lower series of coal-bearing rocks is well exposed in cliffs and high hills north and east of the station. Here as at Black Buttes the base of the exposure is formed by a massive light-colored sandstone about 100 feet thick, and this fact, together with evidence of local faulting along the railroad between the two places, has led several geologists to regard the two exposures as representing about the same horizon. Our observations confirmed those of Meek and Bannister in putting the Point of Rocks coal beds several hundred feet lower than those at Black Buttes, and we discovered the additional fact that a considerable portion of the intervening strata consists of marine beds and contains a Fox Hills fauna. The uneven upper surface of the heavy sandstone at Point of Rocks was regarded by Powell as evidence of an erosion interval which separated the Point of Rocks group below from the Bitter Creek group above. The larger number of the fossil plants described from this locality were obtained in argillaceous lenticular masses in the upper part of the sandstone. Others are associated with the coal beds, of which there are several in the series of soft sandstones, sandy shales, and clays exposed in the bluffs north of Point of Rocks station to a thickness of about 260 feet above the massive sandstone. About the middle of the coal-bearing part of the section two fossiliferous bands have yielded a few species of invertebrates consisting of one marine shell, *Pectunculus holmesianus* (White); four brackish-water forms, *Ostrea glabra*, var. *wyomingensis*, Meek; *Corbula undifera*, Meek; *Corbicula occidentalis*, M. and H., and *Anomia* sp., and one fresh-water form, *Campeloma vetula*, M. and H (?). A lower horizon below the massive sandstone and exposed two miles west of the station has a similar assemblage of forms as follows:

Ostrea glabra, M and H.
Anomia gryphorhynchus, Meek.
Corbicula cytheriformis, M. and H.
Corbula subtrigonalis, M. and H.
Melania insculpta, Meek.
Odontobasis buccinoides, White.

The last-named species is one of the very few marine forms that have been cited as coming from the Laramie.

In the neighborhood of Point of Rocks the dip of the beds is about 6 degrees a little north of east, almost parallel with a valley that joins that of Bitter creek just east of the station, so that the heavy sandstone soon disappears beneath the surface and the beds above it successively come down to the valley level in the hills on its north side, where they are well exposed and may be easily studied. The beds on the top of the bluffs north of the station thus come down to the valley a little over a mile east of that place, and immediately above them, in a brown ferruginous sandstone, the following marine Cretaceous species indicating a Fox Hills horizon were found:

Ostrea glabra, M. and H.	*Mactra alta*, M. and H.
Inoceramus cripsii, var. *barabini*, Morton.	*Mactra warrenana*, M. and H. (?)
Cardium speciosum, M. and H.	*Dentalium gracile*, H. and M.

A few feet below the band containing these fossils a single specimen of *Melania wyomingensis* was found. This and the *Ostrea glabra* are Laramie species, but both have been found in the Fox Hills beds near Longmont, Colorado.

It will doubtless be suggested that these marine beds have been brought to their present position by faulting, but the nature of the exposure is such that this does not seem possible. The horizon may be traced continuously back to the top of the bluffs just north of Point of Rocks, where it is exposed only about 200 yards north of the edge of the bluffs; but fossils are very rare here, consisting of a few small bivalves, among which a *Tellina* was recognized. Above this horizon there are few exposures seen on going eastward until a line of cliffs is reached nearly four miles east of Point of Rocks. These cliffs show at their base about 150 feet of clay shales with bands of sandstone, and a concretion in the clays yielded *Baculites ovatus*, Say.; *Lunatia occidentalis*, M. and H., and *Mactra* sp., showing that this horizon, some 700 feet above the last one mentioned, is still in the Fox hills. The shales are overlain by a massive sandstone somewhat over 100 feet thick, yellowish brown below and nearly white above, and it is succeeded by a series of shales, sandstones, and coal beds like that at Black Buttes, and containing many of the same characteristic species of fossils in the same stratigraphic order. *Ostrea glabra*, var. *arcuatilis*, Meek; *Unio couesi*, White; *Corbicula fracta*, Meek, and *Tulotoma thompsoni*, White, occur in great number. The evidence, we think, is sufficient to identify these beds with those at Black Buttes, a few miles away, and it establishes the position of the Black Buttes horizon considerably above the Point of Rocks beds and immediately above the Fox Hills; in other words, in the position of the true Laramie.

FIGURE 2.—*Section from Point of Rocks Station to Bluffs four Miles east.*

a, Point of Rocks; *b*, Principal plant-bearing beds; *c*, Fox Hills fossiliferous horizon; *d*, Fox Hills fossils at base of cliffs composed of the Black Buttes horizons.

The sketch section (figure 2) from Point of Rocks station four miles eastward to the line of bluffs formed by the Black Buttes horizon shows the stratigraphic relation and position of the fossiliferous horizons.

If our observations and reasoning are correct, the flora of Point of Rocks, which has been spoken of as "somewhat different from that of any other locality in the west," is not a part of the Laramie flora at all, but must be considered as older and comparable with the Fox Hills plants of the Laramie plains and with the Belly River plants of Canada.

ROCK SPRINGS.

The coal-bearing series here exposed from the neighborhood of the Van Dyke mine to the cliffs northwest of the town has a total thickness of 2,000 feet or more and may include both the Point of Rocks and the Black Buttes horizons, though we did not find any marine beds in the section. In the lower portion below the Van Dyke coal the following plants were collected associated with *Corbula subtrigonalis*, M. and H.:

Sequoia brevifolia, Lx.	*Juglans*, n. sp.
Salix sp.	*Rhamnus rectinervis*, Lx.
Ficus tiliæfolia, Al. Br.	*Zizyphus*, n. sp.
Juglans rugosa, Lx.	*Fraxinus* (?), n. sp.

Higher beds have yielded a few invertebrates, most of which have a considerable range in Cretaceous brackish-water strata. They are as follows:

Ostrea glabra, M. and H.	*Corbula undifera*, Meek.
Anomia micronema, Meek.	*Melania insculpta*, Meek.
Modiola regularis, (White).	

EVANSTON AND HODGES PASS.

The Almy mines near Evanston have long been known as coal producers and the geology of the neighborhood is described or referred to in nearly all of the reports cited in the preceding section. Only 500 or 600 feet of the coal-bearing series is exposed here, and its relation to underlying beds is not shown. It is overlain by coarse conglomerates and sandstones of the Wasatch formation, which is probably not conformable, though it has about the same dip at this place. The coal-bearing series itself has been provisionally referred to the Wasatch by Dr White,* and those who have studied its fossil flora have agreed in placing it in the upper part of the Laramie.

A much more satisfactory section of what appears to be the same series, and especially of the underlying beds, may be seen about 50 miles north of Evanston, in the neighborhood of Hams Fork station and Hodges pass, where the Oregon Short Line cuts through the divide between the Green River and Bear River drainage areas. Professor Ward † called attention to it as a plant-bearing locality and suggested its correlation with the Evanston horizon. The lithologic character of the beds, the great thickness of the coal, and the general structure of the region all favor this correlation. The coal series is overlain by reddish conglomerates, sandstones, and shales like those of the Wasatch near Evanston, and still higher the light-colored Green River shales are well developed and clearly unconformable with all the older beds. The coal-bearing series is here fully 2,000 feet thick and it rests directly on marine Cretaceous beds belonging to the Montana formation, of the facies so well developed at Bear River City, Wyoming, and Coalville, Utah; that is, it has the stratigraphic position of the Laramie, though its upper portion may possibly belong to a later horizon. The prominent Cretaceous sandstone ridge which is called "Oyster ridge" in the Fortieth Parallel Survey reports is about three miles east of Hodges pass, and may be traced continuously for many miles both north and south. Near its western base, at Diamondville, on the railroad, a coal bed is now mined that is much older than those of Hodges pass, though probably belonging to the Montana formation. The apparent thickness of the strata between the two horizons is about 4,000 feet, in which several bands of Cretaceous fossils were found, including *Ostrea coalvillensis*, Meek, and *Inoceramus fragilis*, H. and M. (?), immediately above the Diamondville coal; *Inoceramus erectus*, Meek, *Cardium*, *Cyprimeria*, and *Anomia* from a higher horizon at Hams Fork station, and *Inoceramus* sp. from the top of the clays at the foot of Hodges pass. On the published geological maps of the region all these beds above the sandstone of Oyster ridge are colored as Wasatch.

Other Localities.

CARBON, WYOMING.

In discussing the fossil flora of this place the paleobotanists have usually associated it with that of Evanston, though on account of local

* Bull. U. S. Geol. Survey, no. 34, pp. 9-12.
† 6th Ann. Rep. U. S. Geol. Survey, p. 541.

displacements its relations to well established horizons have always been doubtful. We cannot make any direct contribution to the subject, but four or five miles to the eastward, between Carbon and Allen junction, we observed an older coal-bearing series comparable with that on the Laramie plains and at Point of Rocks. The basin in which the Carbon coal mines are located seems to be formed of the highest strata exposed in the neighborhood. A short distance east of the village the beds have a much steeper dip to the west and appear to pass under the coal series. Several thousand feet of these upturned beds are crossed between Carbon and Allen junction, and near the latter place there are prominent ridges of sandstone, with which there are associated several coal seams and beds of shale. In a higher sandstone band near the Sulphur springs, a little over a mile west of Allen junction, a few marine fossils were collected, including *Mactra* sp., *Scaphites* sp., and *Baculites ovatus*, and a still higher horizon one-half mile farther west yielded *Pectunculus holmesianus*, (White) (?), and *Anomia* sp.

COALVILLE, UTAH.

The interesting section at Coalville has been frequently described and discussed.* Both the Colorado and Montana formations are present and coal-bearing, and at the top of the series are the great conglomerates of Echo canyon referred to the Wasatch. The Laramie has not been recognized in the section, though it may possibly be represented by barren strata between the Wasatch conglomerates and the highest marine strata. It would not be within the scope of the present discussion to consider the whole Coalville section, but in connection with the similar occurrences here recorded we wish to call attention to the plant-bearing horizon near Coalville in the Montana formation, fully 1,800 feet below the top of the marine Cretaceous.† The plants are mostly Laramie species, and would have been assigned to that formation in the absence of stratigraphic evidence. The following is the list:

Sequoia longifolia, Lx.
Sequoia reichenbachii, Heer.
Glyptostrobus europæus (?), Heer.
Salix elongata, O. Web.
Salix integra, Göpp.
Salix sp.
Ficus lanceolata, Heer.
Ficus planicostata (?), Lx.
Ficus irregularis (?), Lx.
Platanus marginata, (Lx.) Heer.
Viburnum sp.
Cinnamomum affine, Lx.
Magnolia tenuinervis, Lx.

CROW CREEK, COLORADO.

The Laramie beds on Crow creek, 25 miles northeast of Greeley, Col-

*An account of the stratigraphy and paleontology with references to the literature may be found in Bull. U. S. Geol. Survey, no. 106, pp. 37-44.
†Bull. U. S. Geol. Survey, no. 106, pp. 38, 42.

orado, have been described by Dr C. A. White.* Some of the fossils obtained there also occur in the Denver beds, in the Ceratops beds of Converse county, and at Black Buttes, and it has been suggested that possibly the Denver or Arapahoe beds, as well as the Laramie, might be represented there. We found fairly good exposures near the Canfield ranch and four or five miles above it, in the neighborhood of a large irrigation reservoir. Fossils were distributed through the 40 or 50 feet of beds exposed, and they are associated throughout in such a way as to remove all doubt as to the unity of the formation, which is certainly of Laramie age. This conclusion received additional confirmation from a few species of plants found at the base and near the top of the exposure.

General Considerations.

BASE OF THE LARAMIE.

The facts stated in the preceding pages have an important bearing on the more general question as to the upper and lower limits of the Laramie. King's original definition of the Laramie † as the coal-bearing series that conformably overlies the Fox Hills beds is a simple one, but its practical application in the field is often a difficult matter, especially in areas where there have been alternations of marine deposits with those of fresh or brackish waters in which conditions were favorable for the formation of coal. In speaking of such alternations in Montana, Hatcher ‡ concludes that—

"The terms Fox Hills and Laramie as now used cannot be taken to represent distinct and different periods of time. . . . Marine beds with typical Fox Hills fossils have been found interstratified with fresh and brackish water beds containing characteristic Laramie fossils, showing conclusively that the two periods were, in part at least, contemporaneous."

If this view be adopted, then the term Laramie has no time significance whatever, but simply indicates the conditions under which sedimentation occurred at different times. In western Colorado, Hills met with the same difficulty, but solved it in a different way. He says: §

"For economic reasons, we could wish that the base of the Laramie were made to coincide with the base of the productive coal measures or, what amounts to the same thing, with the lowest strata containing land plants. It may be well to explain, however, that the base of the productive measures does not always include the lowest coal seams exposed. . . . For the present, therefore, as in a former discussion of this question, I shall regard the base of the Laramie as limited by the base

*Ann. Rep. U. S. Geol. Survey Terr. for 1877, pp. 163–174.
† U. S. Geol. Expl. 40th Parallel, vol. i, pp. 298, 331.
‡ American Naturalist, vol. xxx, p. 117, Feb., 1896.
§ Proc. Colo. Scientific Society, vol. iii, pt. iii, 1890, p. 382.

of the productive measures or by the bed of massive sandstone usually found immediately below the lowest coal bed."

The Laramie as thus defined was made to include beds containing marine Cretaceous fossils such as *Inoceramus*. The logical result of such a definition would be a return to the early usage under which all the workable coals of the west were referred to the "Lignitic," and the base of the Laramie would vary at different localities from the Fort Benton to the top of the Fox Hills. Would not the economic considerations be as well satisfied if these older coal beds are called simply Upper Cretaceous, reserving the term Laramie for beds later than the Fox Hills?

It is admitted that owing to the absence or scarcity of fossils it will sometimes be difficult to locate the exact top of the Fox Hills, and, as in the case of Point of Rocks, localities may be known for years before they are assigned to the proper horizon, but such cases are not unknown in other formations. It should be noted that wherever marine fossils have been found above supposed Laramie coal beds they are of Fox Hills species (or Montana species, to use the more general term), and this fact is of more importance in age determination than the occurrence beneath them of "characteristic Laramie species." It is generally admitted that marine invertebrates are more accurate and definite horizon markers than either plants or non-marine invertebrates, because they have a less extended vertical and a broader geographic distribution. We would therefore follow the example of King, Hayden, and many other geologists in placing the base of the Laramie immediately above the highest marine Cretaceous beds of the Rocky Mountain region. We include in the Montana formation or division intercalated non-marine beds that at some localities yield land plants and brackish and fresh water mollusks as well as coal. Whether it will be useful to give local formation names to these coal-bearing beds as has been done with the Belly River series in Canada is a question that may well be left to the field geologist when he takes up their detailed mapping. In Bitter Creek valley Powell's Point of Rocks group would be available after some changes in its boundaries, as it has yielded most of the plants and some of the invertebrates of the lower beds.

It will be instructive to bring together for comparison with the Laramie all the known non-marine invertebrates and the plants associated with the lower coal beds under consideration.

NON-MARINE INVERTEBRATES OF THE MONTANA FORMATION.

It is noteworthy that strictly fresh-water forms are very rare,* being

* The Belly River beds have yielded a considerable fresh-water fauna, consisting mostly of Laramie species with some that continue on into the Fort Union, but as we have no personal knowledge of the stratigraphy of the Canadian beds their fauna will not be considered in detail.

limited to an undetermined *Unio*, a *Melania*, *Valvata nana*, and *Physa carletoni* at Coalville, and the somewhat doubtful occurrence of *Campeloma vetula* at Point of Rocks. In addition two Laramie species of *Melania* are found near Point of Rocks, but associated with marine and brackish-water shells.

Brackish-water forms are more abundant and are mostly of types that persist throughout the upper Cretaceous. Some of the same species occur in the Laramie. At Coalville there is a larger proportion of local species associated with the plants, and with them there are a few that belong to marine genera. The following species, in addition to the fresh-water forms already noted, have been collected there from the same horizon:

Ostrea coalvillensis, Meek.
Anomia propatoris, White.
Modiola multilinigera, Meek (?).
Cyrena carletoni, Meek.
Corbicula sp.
Avicula sp.
Corbula subtrigonalis, M. and H.
Turritella spironema, Meek.
Neritina bellatula, Meek.
Neritina carditoides, Meek.
Neritina bannisteri, Meek.
Eulimella (?) *chrysallis*, Meek.
Eulimella (?) *inconspicua*, Meek.

From the neighborhood of Point of Rocks the following species have been obtained:

Ostrea glabra, M. and H.
Ostrea glabra, var. *wyomingensis*, Meek.
Anomia gryphorynchus, Meek.
Corbicula cytheriformis, M. and H.
Corbicula occidentalis, M. and H.
Odontobasis buccinoides, White.
Pectunculus holmesianus, (White).

The last two species of the list belong to marine genera, though they are associated in the same layers with others which may live in either marine or brackish waters. Two other marine species, *Nuculana inclara*, (White), and *Odontobasis* (?) *formosa*, White, that have been described as coming from the Laramie of northwestern Colorado, are most probably also from a lower horizon, so that no strictly marine species are left in the Laramie fauna.

FOSSIL PLANTS OF THE MONTANA FORMATION.

The following is a complete list* of the fossil plants which have been found at Point of Rocks below the marine Cretaceous:

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* The species marked with a * are confined to these beds, while those marked with a † are open to question either as to their identification in the Point of Rocks beds or at the other localities from which they have been reported. Only the unmarked species have an unquestioned distribution outside of the Point of Rocks beds.

†*Anemia subcretacea*, (Sap.) Gard. & Ett.
Cissus lobato-crenata, Lx.
†*Carpites triangulosus*, Lx. [of no value].
†*Cornus impressa*, Lx.
†*Cornus rhamnifolia*, O. Web.
†*Cornus studeri* (?), Heer.
Diospyros brachysepala, Al. Br.
**Dryophyllum crenatum*, Lx.
Dryophyllum subfalcatum, Lx.
**Ficus asarifolia*, Ett.
Ficus dalmatica, Ett.
**Ficus*, n. sp.
Ficus irregularis, Lx.
**Ficus*, n. sp.
**Ficus*, n. sp.
**Ficus*, n. sp.
**Ficus*, n. sp.
†*Ficus tiliæfolia*, Al. Br.
**Ficus*, n. sp.
**Ficus*, n. sp.
†*Fucus lignitum*, Lx.
**Ginkgo laramiensis*, Ward.
Grewiopsis cleburni, Lx.
Halymenites major, Lx.
**Laurus præstans*, Lx.
†*Laurus primigenia*, Ung.
**Liriodendron laramiense*, Ward.
**Litsea*, n. sp.
**Lycopodium lesquereuxiana*, Kn. (*Selaginella falcata*, Lx. ex. p.)
**Magnolia puchra*, Ward.
Myrica torreyi, Lx.
**Ottelia americana*, Lx.
**Pistia corrugata*, Lx.
†*Platanus marginata*, (Lx.) Heer.
†*Podogonium americanum*, Lx.
Populus arctica, Heer.
**Populus melanarioides*, Lx.
Populus mutabilis ovalis, Heer.
**Pterospermites*, n. sp.
**Pterospermites*, n. sp.
†*Quercus dentoni*, Lx.
**Rhus membranacea*, Lx.
†*Sabalites grayanus*, Lx.
†*Salix angustata*, Al. Br.
**Salvinia attenuata*, Lx.
**Selaginella falcata*, Lx. ex. p.
**Selaginella laciniata*, Lx.
**Sequoia biformis*, Lx.
**Sequoia brevifolia*, Lx.
Sequoia longifolia, Lx.
Sequoia reichenbachi, Gein.
Trapa (?) *microphylla*, Lx.
†*Viburnum dichotomum*, Lx.
**Widdringtonia* (?) *complanata*, Lx.
**Woodwardia*, n. sp.

From this list it appears that Point of Rocks has a flora of 55 species, of which number 28 have not been found elsewhere. Of the remaining 27 forms 14 are open to question, leaving only 13 having an unquestioned distribution in other horizons, and of these latter at least two (*Halymenites major* and *Sequoia reichenbachi*) have a distribution ranging through nearly the whole of the Cretaceous. The number of outside species is therefore reduced to 11, which is really very small when we take into consideration the size of the flora and its supposed affinities with the true Laramie.

On page 150 we have given a list of the plants found at Coalville, Utah, some 1,800 feet below the top of the marine Cretaceous. It embraces 13 forms, of which 5 are either doubtful or not specifically determined. Of the 8 remaining, 4 are also found at Point of Rocks, and two species additional (*Salix elongata* and *S. integra*) are not entitled to much consideration from the fact that they are not easily identified in any formation.

From the localities in the vicinity of Harper station, on the Laramie plains, the following species have been detected:

Anemia subcretacea, (Sap.) Gard. & Ett.
Sequoia reichenbachi, Gein.
Brachyphyllum, n. sp.
Salix sp.
Spathites, n. sp. (?).
Myrica torreyi, Lx.
Quercus acrodon, Lx.
Ficus planicostata, Lx.
Cinnamonum affine, Lx.
Celastrus, n. sp.

Of these 10 species 4, including 3 new to science, have not been found outside these beds, while all of the remaining species have been found in either the Point of Rocks or Coalville beds.

From the foregoing presentation it appears that the flora of the Montana formation embraces at least 67 species.

TOP OF THE LARAMIE.

Until a few years ago it was the custom to include in the Laramie all of the beds between the Fox Hills and Wasatch formations. In the Denver region the detailed studies of Cross and Eldridge,* already referred to, have resulted in the recognition of the Arapahoe and Denver beds separated from the Laramie and from each other by unconformities and distinguished by marked lithologic features. A revision of the fossil floras of that region has also shown that the Denver beds contain a flora composed of species a large proportion of which are not found in the underlying Laramie. Cross,† Hills,‡ and others have observed that beds lithologically resembling the Denver bed and in a similar stratigraphic position above the Laramie occur at several widely separated localities in western and southwestern Colorado. In southern Montana Weed § has defined the Livingston formation as a very thick series of strata lithologically comparable with the Denver beds, resting unconformably on the Laramie and yielding a small flora more closely related to the Denver flora than to any other. The same geologist || also finds beds that he refers to the Fort Union, overlying the Livingston. All these formations are older than the Wasatch, and we should naturally expect to find them in eastern and southern Wyoming, or, if they are absent there, their places should be indicated by unconformities.

The Denver and Arapahoe beds have yielded representatives of a remarkable reptilian fauna consisting largely of horned dinosaurs of the family Ceratopsidæ. The presence of this family in the Ceratops beds of Converse county and probably at Black Buttes has suggested the

* Proc. Colo. Sci. Soc., vol. iii, pt. i, pp. 86–133 ; Am. Jour. Sci., 3d ser., vol. xxxvii, 1889, pp. 261–282 ; Monograph xxvii, U. S. Geol. Survey (in press).

† Am. Jour. Sci., vol. xliv, 1892, pp. 19–42.

‡ Proc. Colo. Sci. Soc., vol. iii, pt. iii, 1890, pp. 390–397.

§ Bull. U. S. Geol. Survey, no. 105, pp. 21–37.

|| Am. Geologist, vol. xviii, pp. 201–211, October, 1896.

very reasonable query whether the beds containing them at these places also are not younger than the true Laramie. The facts we have presented relative to the stratigraphy and paleontology of the Black Buttes dinosaur horizon seem to us convincing that it is in the Laramie and near the base of that formation. It is less than 200 feet above the marine Cretaceous, and there is no evidence of a break* nor any abrupt lithologic change. The character of the flora and of the invertebrate fauna also, so far as the species have a distribution in recognized horizons elsewhere, favors its reference to the Laramie. If the Dinosaur bed of Black Buttes is not Laramie, then the Laramie is either absent or is represented only by about 100 feet of sandstone. The overlying beds up to and including strata with a Fort Union flora seem to form a continuous series that is indivisible either structurally or lithologically, and we can see no reason for placing the top of the Laramie lower than the base of the lowest bed with a Fort Union flora.

Closely similar conditions are seen in Converse county, the principal difference being a greater development of the beds. The sandstones at the base overlying the Fox Hills are a few hundred feet thick, and the variable, more argillaceous, higher beds, with a fresh-water fauna in large part identical with that at Black Buttes and a flora that also indicates the same horizon, have a much greater thickness. Here again there seems to be no break in a series that has Fort Union plants in its upper member. The abundant occurrence of such a species as *Campeloma multilineata* throughout all but the lowest portion of the series argues strongly for continuous sedimentation.

The difficulty of recognizing unconformities in beds so little disturbed has not been overlooked, and the possibility that there may be such undiscovered breaks in these two areas is freely admitted, though it does not seem to us probable. From the facts now available it seems most probable that in Converse county and in the Bitter Creek valley the time representatives of the Denver and Arapahoe beds are undifferentiated portions of a continuous series and cannot be separated from the Laramie.† The Fort Union beds are apparently distinguishable by means of their flora, and these mark the upper limit of the Laramie in the areas in question.

* The supposed unconformity between Powell's Point of Rocks and Bitter Creek groups has no bearing on this question, since it is below marine beds belonging to the Fox Hills.

† This is essentially the view suggested by Dr C. A. White in Bull. U. S. Geol. Survey no. 82, p. 150.

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WEATHERING OF MICACEOUS GNEISS IN ALBEMARLE COUNTY, VIRGINIA

BY GEORGE P. MERRILL

(*Read before the Society December 31, 1896*)

CONTENTS

INTRODUCTION.

In previous papers the writer has endeavored to show the changes taking place in the preliminary stages of rock-weathering as illustrated in the post-Cretaceous and post-Glacial disintegration of the granites of the District of Columbia and the diabase of Medford, Massachusetts.* The purpose of the present paper is to discuss the results of similar processes, operating for longer periods, and incidentally to refer to other matters with which the subject is closely affiliated.

The material selected for investigation is a highly micaceous, feldspar-rich gneissoid rock and its residual clay, occurring at North Garden, in Albemarle county, Virginia. The region lies to the west of the Cretaceous submergence, the accumulated gravels of which enabled us to set an approximate time limit to the weathering manifested in the District of

* Disintegration of the Granitic Rocks of the District of Columbia, Bull. Geol. Soc. Am., vol. 6, 1895, pp. 321-332, and Disintegration and Decomposition of Diabase at Medford, Massachusetts, ibid., vol. 7, 1896, pp. 349-362.

Columbia rocks, and thus no criteria are afforded for estimating the relative rapidity of the process. The amount of material lost through leaching and erosion is obviously large, but at the locality from which the materials for study were selected, the fresh rock was still overlaid by several feet of residuary matter in the form of sand, gravel, and clay, which constitute the prevailing soil of the region. Although very plastic when wet, and inclined to cake during seasons of drought, this soil is nevertheless fairly fertile and easily cultivated.

Petrographic Features of the fresh Rock.

In its least changed condition—the best material obtainable from available outcrops—the rock is a highly feldspathic gneiss carrying abundant folia of black mica. Under the microscope it shows an extremely variable, sometimes cataclastic structure. Both orthoclase and soda-lime feldspars are present, the latter being often fairly clouded with enclosures of minute zircons. These last are so small as to have their optical properties quite obscured by those of their host, but can be washed from the residual sand in quantities and readily determined. The largest forms obtained thus measured some .12 by .4 millimeters, the average being perhaps .06 by .30 millimeters. Black mica is very abundant, as noted above, and quartz occurs in the usual granular forms. There is the usual sprinkling of iron ores and apatites, and in addition small garnets, and in considerable quantity a soda-potash bearing zeolite occurring in dense aggregates and radiating masses, almost wholly without action on light and with crystal outlines so poorly developed as to make their true mineralogical nature, except by microchemical tests, a matter of surmise. A bulk analysis of the rock and also one of the portion decomposed by boiling hydrochloric acid is given in columns 1 and 2 below.

Physical Manifestations of Weathering.

In weathering the rock becomes brownish and friable, passing into the condition of a loose agglomerate of angular gneissic fragments, so discolored by decomposition as to be scarcely recognizable, and imbedded in fine brown sand and dust. Finally, on the immediate surface the rock has weathered to a red, tenacious clay, which still retains a sufficient quantity of undecomposed silicates and of free quartz to have a distinct gritty feeling when rubbed between the hands. Under the microscope it shows sharply angular fragments of quartz and feldspar, numerous folia of black mica, and much opaque or amorphous matter so stained by iron oxides and decomposition products as to quite obscure its true mineral nature. The state of mechanical subdivision of the material is made apparent by the following table, for which, as on previous occasions, I am indebted to Dr Milton Whitney, of the Department of Agriculture.

Mechanical Analysis of residual Soil.

Diameter (in millimeters).	Conventional names.	Per cent.
(1.) 2–1	Fine gravel	1.15
(2.) 1–.5	Coarse sand	2.92
(3.) .5–.25	Medium sand	6.29
(4.) .25–.1	Fine sand	17.42
(5.) .1–.05	Very fine sand	15.60
(6.) .05–.01	Silt	7.65
(7.) .01–.005	Fine silt	1.83
(8.) .005–.0001	Clay	35.73
Total mineral matter		88.59
(9.) Loss at 110° C.		2.93
(10.) Loss on ignition		8.49
Total		100.01

Chemical Analyses and their Discussion.

Below is given the analyses of the fresh rock and residual soil, together with that of the portion decomposed by boiling hydrochloric acid, while in columns 6, 7, and 8 are given calculations from the analyses in columns 1 and 3 to show the total loss of material and also the percentage amounts of each of the original chemical constituents saved and lost. These calculations, as in previous papers, are made on the assumption that the alumina has remained essentially constant, and though nothing like absolute accuracy can be claimed for the results, they are by no means uninteresting and uninstructive.

The particular features to which attention need here be called are (1) that 30.51 per cent of the fresh rock and 69.18 per cent of the decomposed are soluble in hydrochloric acid and sodium carbonate solutions, and that more than half the potash and nearly the same proportion of the soda in the fresh rock is found in the acid extract; (2) that the insoluble portion of the residuary material is mainly in the form of free quartz; (3) that 44.67 per cent of the original matter has been leached away, and that (4) of the original silica, 52.45 per cent is lost, while 85.61 per cent of the iron and all the alumina* remain. All the lime has disappeared; 83.52 per cent of the potash, 95.03 per cent of the soda, and 74.70 per cent of the magnesia. The total amount of water, as indi-

* This is not absolutely correct, since all the alumina was assumed to have remained in order to give a basis for calculations.

Chemical Analyses of fresh and decomposed Gneiss.

Contents.	Fresh gneiss.		Decomposed gneiss.			Calculated amounts saved and lost.		
	1	2	3	4	5	6	7	8
	Bulk analysis.	Analysis of portion soluble in HCl and Na_2CO_3.	Bulk analysis.	Analysis of portion soluble in HCl and Na_2CO_3	Analysis of insoluble portion.	Loss.	Percentage of each constituent saved.	Percentage of each constituent lost.
Silica (SiO_2) in HCl	60.69 (both)	1.43	45.31 (both)	0.55	28.90 (both)	31.90	47.55	52.45
Silica (SiO_2) in Na_2CO_3		8.66		17.14				
Alumina (Al_2O_3)	16.89	13.54 (alumina and iron)	26.55	24.86	1.55	0.00	100.00	0.00
Iron sesquioxide (Fe_2O_3)	9.06		12.18	11.80	0.22	1.30	85.65	14.35
Lime (CaO)	4.44	1.64	Trace.	0.06	0.07	4.44	0.00	100.00
Magnesia (MgO)	1.06	0.89	0.40	0.37	0.04	0.80	25.30	74.70
Potash (K_2O)	4.25	2.40	1.10	0.75	0.31	3.55	16.48	83.52
Soda (Na_2O)	2.82	1.10	0.22	0.25	Trace.	2.68	4.97	95.03
Phosphoric acid (P_2O_5)	0.25	0.23	0.47	....	Trace.	0.00*	100.00	0.00*
Ignition	0.62	0.62	13.75	13.40	0.35	0.00*	100.00	0.00*
	100.08	30.51	99.98	69.18	31.44	44.67	....	....
				100.62 (4 + 5)				

* Gain.

cated by the ignition, has increased very greatly, as was to be expected. The small original amount of phosphoric acid prohibits our placing too much reliance upon an indicated gain of the fraction of one per cent in this constituent, since it may be due to errors in manipulation.

On the assumption that such calculations always yield results rather under than above the amount of material actually lost, I have assumed from this and other analyses available that a silicious crystalline rock of the granitic or more basic type in passing into the condition of a residual clay or soil, as the word is ordinarily used, loses about 50 per cent of its original constituents through solution and the leaching action of meteoric waters.*

Cause of Red Color of the Soil.

The pronounced red color of this residuary material is worthy of consideration. It will be remembered that the cause of this striking difference in the color of superficial deposits in northern and southern latitudes has been the subject of much discussion, the names of Professors W. O. Crosby,† I. C. Russell,‡ and J. D. Dana § being most conspicuous in existing literature. Professor Crosby argued that the intense color was purely superficial and due to a dehydration of the ferric salts with which the soils are impregnated, whereby the color was changed from yellow and brown to red, the cause of the hydration being the long continued higher temperatures to which the superficial portions were subjected in the lower latitudes. It is not necessary to go into a detailed discussion here of all the points involved in the controversy, but I wish to state that my own observations are entirely in accord with those of Professor Crosby, so far as the superficial character of the phenomenon is concerned. In some cases the brilliant color is found as a mere wash, or again it penetrates to the depth of a foot or more before giving way to more modest hues. In such instances the colors have penetrated most deeply along joint planes or other lines of weakness, leaving the intervening compact masses of more somber shade. The gradual transition from the surface downward, from bright red to brown, yellow, or gray, may be seen to have taken place, usually within the space of a few vertical feet, in any new road or railway cut, but becomes quickly obscured, even by the first rainfall, through the washing down of the ochreous coloring matter from above.

That the increased color in the superficial portions is due wholly to dehydration of the ferric salts, the writer is disposed to doubt. It must

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* See Rocks, Rockweathering, and Soils. The Macmillan Company, New York, 1897.

† Proc. Boston Soc. of Nat. Hist., vol. 23, 1875, and Am. Geologist, August, 1891.

‡ Bull. U. S. Geol. Survey, no. 52, 1889.

§ Am. Jour. of Science, vol. 39, 1890, pp. 317-319.

be remembered that the color imparted to a bed of sand or clay depends not merely upon the quality of the coloring constituent, but also upon its quantity. This is well shown in the fractional separations made by washing these residual clays and sands, whereby they are separated into proportional parts of varying degrees of fineness. Thus the disintegrated diabase of Medford, Massachusetts, described by the present writer at a previous meeting,* is of but a dull brown-gray color, yet the finest silt separated out by washing, and which is but a ferruginous clay, is of a distinct brown-red color. A larger amount of this fine material would naturally impart a more decided brown-red color to the residual sand.

Now, rock-weathering in warm, moist climates in particular, is accompanied by a leaching process, as I have elsewhere pointed out,† whereby the more soluble constituents are gradually removed. But, of all those constituents occurring in essential quantities in ordinary rocks the ferric salts and the alumina are most refractory; hence the final product of decomposition is a highly ferruginous clay—a clay composed essentially of a mechanical admixture of hydrous aluminous silicates, free silica, and free sesquioxides of iron—and its color is due to the preponderance of this free oxide which has become segregated through the leaching out of the more soluble constituents. While not taking exception to the view advanced by Professor Crosby to the effect that the iron in these southern soils may exist in a state of partial dehydration, I would account in part for the brilliancy of color merely through the presence of this excess of coloring matter. Color is then indicative of advanced decomposition and, other things being equal, of geological antiquity. This view is rendered the more plausible when it is recalled that the post-Cretaceous decay of the granites of the District of Columbia, to which I have previously called attention, has in most cases given rise to residual sands and clays of but a gray-brown color, while rocks of a precisely similar nature, decaying under the same climatic conditions, but so situated that the products of decay have been allowed to accumulate for longer periods, give rise to colors of characteristic brilliancy.

Zeolites in the fresh Rock and their possible Origin.

The occurrence of zeolites in the still fresh rock and the proportionately large amount of soluble matter in both the rock and the residual soil brings up for consideration the probable form in which these soluble constituents exist. Those at all conversant with the literature of the subject will at once recall the work of Lemberg, Hilgard, and others and the conclusions reached regarding the formation of zeolites during the

* Bull. Geol. Soc. Am., vol. 7, 1896.
† Rocks, Rockweathering, and Soils. The Macmillan Company, New York, 1897.

processes of rock-weathering and rock decomposition, and also the probable efficacy of these zeolites as conservators of potash in such form that it becomes available for plant food. It is unnecessary to here go into a discussion of the literature or even to more than briefly refer to the causes which have led to these conclusions. The fact that soda and potash can, in laboratory practice, be made to mutually replace each other in gelatinous precipitates of aluminum or magnesium, as well as in true zeolitic compounds, taken together with the ready decomposability of zeolites by weak acids and the presence in soils of easily decomposable compounds of these bases, are the main grounds for the assumption. So far as the writer is aware, no one has as yet actually proved either the formation of zeolites during the process of true weathering or of their existence in the weathered product in other than fragmental forms as detrital products from the breaking down of zeolite-bearing rocks.

As yet much is to be learned regarding the formation of zeolites. So far as can be judged from available information, they form most readily, if not invariably, in the presence of continual moisture and where protected from oxidizing influences. Synthetic experiments have shown that zeolites may be formed in sealed tubes during a comparatively brief period at temperatures of not above 150 to 200 degrees centigrade. The inference is fair that, given a longer time, they will form at lower temperatures, provided, of course, other conditions are favorable. In looking over the literature of the subject, in connection with my work on rock-weathering, I have, however, become impressed by the fact that a possibility has been too generally accepted as a probability, and, further, that the terms *weathering*, *decomposition*, and *zeolites* have been used so loosely that their exact significance is lost, and statements made are therefore frequently either misleading or incomprehensible.

Use of the Term Weathering.

First as to the use of the term weathering. It is evident at once that this name should include only those physical and chemical changes in rock masses induced by atmospheric agencies, by temperature changes, and by the chemical action of water and absorbed gases and salts. It is a process which works from above downward, and which manifests itself mainly in a physical disaggregation of the rock and a hydration and oxidation, often accompanied by solution of its various constituents. Such action presumably can be carried on to a depth dependent upon the permanent water level, where it practically ceases. Below this level hydration and other chemical changes may be going on whereby new minerals are generated, but the final results are of a quite different nature. In the upper zone, that above the water level and which may be called the zone of oxidation, the weathering is manifested by a physical breaking down of the rock mass as a geological body, whereby it is resolved into gravel, sand, silt, and clay; a more or less complete change in the character of the chemical compounds usually accompanies this disintegration.

In this latter process there is invariably a tendency toward simplification, complex silicates being broken up and their various elements recombined as simpler hydrous silicates, carbonates, oxides, sulphates, free silica, etcetera. It is to a certain extent comparable with the entire demolition of a building and the utilization of the old material in the construction of new ones of quite different architectural types. The deeper-seated process, on the other hand, is not destructive, but is to a certain extent comparable with that of here and there substituting new materials for old in a structure the general features of which are not otherwise changed. New minerals are formed to replace, wholly or in part, those that preexisted, but the rock retains its geological identity, and in many cases is rendered even more enduring when actually exposed to weathering influences than before. Among the minerals thus formed are zeolites, epidote, amphiboles, feldspars, free quartz, chalcedony, etcetera.

It is obvious that we have here two distinct processes which, while they may grade into each other, are widely separable in their extremes, both as to methods and results. Both unfortunately have been frequently grouped under the general name of weathering and still more frequently under the far more general name of decomposition.

It would seem to the present writer that the name weathering should be limited to those processes going on within the zone of oxidation and resulting as a rule in the destruction of a rock mass as a geological body, while the more deep-seated processes, which are really of mineralogical rather than geological moment, should be looked upon as metamorphic. Hydrometamorphism is sufficiently explicit, though the process in many instances is metasomatic. Roth * makes some attempt at discrimination in calling the deep-seated process "complicirte verwitterung," in distinction from the ordinary superficial "verwitterung;" but this name can scarcely be considered as satisfactory, much less so in fact than our term alteration, as commonly used.

Formation of Zeolites in Soils.

Second, as to the formation and existence of zeolites in the soil. From all that is known regarding the actual formation of zeolites, it appears that moisture and an absence of oxidizing agents is essential. They are

* Allegemeine und Chemische Geologie, vol. 1, p. 159.

products of hydrometamorphism and not those of weathering, as limited above. It is even questionable if the processes involved in weathering are not entirely opposed to zeolitic formation, and destructive rather than otherwise. The processes which result in the breaking up of such minerals as the feldspars, micas, amphiboles, and pyroxenes would certainly quickly destroy a compound of the zeolitic type, even if once existing. Again, the close juxtaposition of mineral particles, such as is favorable to the production of "reaction rims," is quite obliterated in the process of weathering and soil formation. In weathering, the amount of interstitial space is continually augmented, until it amounts to practically 50 per cent, by bulk, of that of the soil itself, as shown by Dr Whitney and by the present writer.*

The fact, moreover, that zeolites are met with in the finest stages of development in cavities of basic eruptive rocks where there are no signs of such decomposition products as are incidental to weathering, and almost wholly lacking in secondary rocks, are facts which should not be overlooked in this connection.†

If formed in soils, why should they not be found in secondary rocks resulting from the reconsolidation of materials derived by the same processes and from similar rocks?

Efficacy of Zeolites as Conservators of Potash.

Third, can zeolites, even if occurring in soils, be considered as of practical value as conservators of potash?

Among the twenty-three known species of zeolites (including apophyllite), in but five is potash considered an essential constituent. These five are enumerated below in tabular form:

Name.	Composition.					
	SiO_2.	Al_2O_3.	CaO.	K_2O.	Na_2O.	H_2O.
Apophyllite	53.7	....	25.0	5.2	....	16.1
Ptilolite	70.0	11.9	4.4	2.4	0.8	20.5
Mordenite	67.2	11.4	2.1	3.5	2.3	13.5
Phillipsite	48.8	20.7	7.6	6.4	....	16.5
			BaO.			
Harmotome	47.1	16.3	20.6	2.1	....	14.1

* Bull. Geol. Soc. Am., vol. 6, p. 332.

† The formation of zeolitic compounds in amygdaloidal cavities of basic eruptives is commonly regarded as due to the action of waters heated by the hot lavas into which they were infiltrated or by water supplied from volcanic sources. See Geikie: Basalt Plateau of Northwestern Europe, Quar. Jour. Geol. Soc. of London, May, 1896, and authorities there quoted.

It will be noted at once that even in these five potash plays a comparatively insignificant part, being highest in phillipsite (6.4 per cent), and averaging for all a little less than 4 per cent. Assuming, then, that a soil contained as high as 10 per cent of zeolitic material all belonging to these five groups and none to the potash-free varieties, even then we would have this combined only some 0.4 per cent of K_2O. It appears to the writer that these figures are sufficient to throw considerable doubt on the subject of either the presence or the utility of zeolites in soils. It is possible that in nature the process of potash replacement as performed in the laboratory has gone on, and that there may exist in the soil zeolitic compounds richer in potash than are at present known to the mineralogist. Such a condition, however, can not be considered probable.

Reference should be made in this connection to the use of the term zeolite as found in the American literature bearing upon soil fertility.

It is apparent that the word is, in only too many instances, used almost wholly without regard to its mineralogical significance, and made to include a considerable variety of secondary hydrous minerals. One writer refers to the magnesia in soils as being in zeolitic combinations, and still another includes glauconite under this head. So comprehensive a usage is objectionable, since the word has a fairly well defined mineralogical significance. If the chemists so extend it as to include glauconite, it can be made also to include serpentine, talc, and even kaolin, and the word becomes of so little significance as to be useless.

Proportional Amounts of soluble Matter in fresh and decomposed Rocks.

There is an abundant opportunity for more work in the way of ascertaining the proportional amount of soluble matter in rocks and in soils which result from their breaking down. As the writer has pointed out,* there may, particularly among basic rocks rich in magnesia, be actually a larger percentage of matter soluble in hydrochloric acid and sodium carbonate solutions in the undecomposed rock than in the soil. This, for the simple reason noted in the paper above referred to, namely, that the decomposition is accompanied by a leaching process, whereby soluble compounds are removed by atmospheric waters. Even in cases where the actual percentage of soluble matter is greatest in the soil, the apparent excess may be due to water of hydration and to the large amount of sesquioxide of iron in the latter, the last, while practically insoluble in meteoric waters so long as there is a free supply of oxygen, being readily soluble in hydrochloric acid. In order to emphasize this point I have tabulated below the analyses of the soluble and insoluble portions of

* Bull. Geol. Soc. Am., vol. 7, 1896, p. 353.

Proportional Amounts of fresh and decomposed Rocks Soluble in boiling Hydrochloric Acid and Sodium Carbonate Solutions.

	Phonolite.		Diabase.		Basalt (Absarokite).		Gneiss.		Granite.	
	Marienfels, Bohemia.		Medford, Mass.		Fort Ellis, Mont.		Albemarle Co., Va.		District of Columbia.	
	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.	Fresh.	Decomposed.
SiO_2	21.64	17.98	10.85	9.50	20.90	19.90	10.09	17.69	9.49	
Al_2O_3	10.37	11.26	4.74	4.86	3.89	5.80		24.86		
Fe_2O_3	2.23	2.72	10.91	10.00	FeO 4.28 2.21	7.81	13.54	11.80	8.36	
CaO	1.07	1.01	3.09	1.50	1.01	1.59	1.64	0.06	0.60	25.37
MgO	0.40	0.44	2.20	1.84	16.42	6.88	0.89	0.37	0.71	
K_2O	0 28	0.11	1.21	0.68	Not det.	0.08	2.40	0.75	1.68	
Na_2O	5 45	0.06	0.50	0.17	Not det.	0.22	1.10	0.25	0.68	
H_2O	4.10	8.78	2.73	3.07	5.42	12.34	0.62	13.40	1.23	
	45.54	42.36	36.23	31 62	54.13	54.62	30.28	69.18	22.75	25.37

fresh and decomposed rocks, so far as available material was at hand, the loss on ignition, minus the loss in the fresh rock, being tabulated as water and calculated as one of the soluble constituents.

The series given is not large enough to permit safe generalizations, but it is sufficiently large and varied to be more than merely suggestive, particularly when we compare these figures with those representing the "insoluble residues" of ordinary soil analyses, and which vary between 55 and 80 per cent in those rich in free lime carbonates and organic matter and between 65 and 90 per cent in others.

Possible Form of Combination of Soluble Constituents.

The possible form of combination of these soluble constituents is certainly an interesting question. Undoubtedly a large part of the iron exists as free hydrous oxides. The small amounts of lime and magnesia may exist partly as carbonates, and a part of the silica has been dissolved from the free quartz by the alkaline carbonate used for the extraction of the gelatinous silica after digesting in acids. Undoubtedly, too, a portion of all the constituents is derived from the partial decomposition by the acid of a variety of existing silicates—shreds of mica, hornblende, augite, flakes of feldspar, etcetera—shown by the microscope to be still existing. Eliminating from consideration in the analyses of the decomposed Bohemian phonolite and Virginia gneiss the Fe_2O_3, and noting only those other constituents found in sufficient quantities to be considered essential, we shall get, by calculating back to a basis of 100, formulæ approximating $Al_2Si_3O_3 + 5\ H_2O$, and $Al_2SiO_5 + 3\ H_2O$, respectively, suggestive of compounds allied to montmorillonite and allophane. The possible errors in these calculations are so obvious that it is unnecessary to enumerate them, but they are of interest, and sufficient to suggest a possible combination of these soluble constituents other than those of zeolites.

It would appear to the writer that the soluble potash in soils exists, not in zeolitic compounds, but in some of the numerous decomposition (?) products of feldspar, nepheline, scapolite, etcetera, to which the name *pinite* is commonly applied. Such at least is the case in the potash-rich soil of Maryland examined by R. L. Packard.*

These remarks are made, not with a view of individual criticism, but to call attention to points which seem in danger of being overlooked.

The writer, assuming that his mental processes are similar to those of other workers, and that language used and statements made in such form as to convey to him erroneous or misleading impressions are likely to produce the same results on others, believes that the using of certain terms with a meaning more precise is a subject worthy of consideration.

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* Bull. 21, Maryland Agricultural Experiment Station, 1895.

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THE LEUCITE HILLS OF WYOMING*

BY J. F. KEMP

(*Read before the Society December 29, 1896*)

CONTENTS

General Review of the Occurrence of Leucite.

The mineral leucite is not a rock-maker of the first magnitude, but it has nevertheless attracted special interest because of its abundance where found. This latter characteristic places it in the group of feldspathoids, which in a minor way have the same important relations to the classification of igneous rocks as do the feldspars themselves. It is the general impression that up to 1868 but three leucite localities were known,†

* In the field-work on which this paper is based the writer has been assisted by Mr Charles A. Fulton, one of his students, and by Mr O. A. Kennedy, of Ogden, Utah, to both of whom acknowledgments are here made.

† It is stated by E. Kalkowsky in a review of a paper by V. Steinecke, entitled "Ueber einige jüngere Eruptiv-gesteine aus Persien," which was published in the Zeitschrift für Naturwissenschaften, iv Folge, Band vi, pp. 1-71, Halle, 1887, and which is not accessible to the writer, that Loftus had made known the occurrence of leucite near lake Urmia, in Persia, in 1850. ("Aus dieser Gegend hatte bereits Anfangs der fünfziger Jahre Loftus das Vorkommen von Leucit erwähnt.") This would modify the above sweeping statement. See Neues Jahrbuch., 1889, vol. i, p. 438.

namely, the Italian volcanoes, especially Vesuvius, the Laacher See, and the Kaiserstuhl in the Black Forest. Humboldt described the mineral as essentially a European one. The introduction of the microscope, and especially its employment by Zirkel in the preparation of his work on the basaltic rocks,* brought to light a number of other localities in Saxony, Bohemia, Thuringia, and the Rhön mountains,† all of which were, however, European. In 1874 it was discovered by Vogelsang in a basaltic rock from the small island of Bawean, north of Java, and the announcement was made the next year by Zirkel,‡ the literary executor of his friend Vogelsang, who had passed away in the meantime. Its next discovery was in rocks from the locality that furnishes the subject of this paper, and was announced in 1876 § by Zirkel, since which date the following additional localities have been successively made known: By Doelter,|| from Monte Ferru, Sardinia, in 1878, in a basaltic lava; by Lorié, from the volcano Ringgit, in eastern Java, in 1879;¶ on Sao Antao, one of the Cape Verde islands, by Doelter,** in 1882, in a leucitite; from the volcano Moeriah, in central Java, by Verbeek and Fennema,†† in 1882; in northwest Persia by Pohlig,‡‡ in 1884, in a leucitophyre; from the Cerro de las Virgines, in Lower California, by von Chrustschoff, §§ in 1884; in Argentina by G. Lallemand, |||| in 1884. So-called pseudomorphs of feldspar, after leucite, were reported from Magnet Cove, Arkansas, by G. F. Kunz,¶¶ in 1885, and were afterward investigated by J. Francis Williams in 1890, by whom they were called pseudoleucites.

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*Untersuchungen über die mikroskopische Zusammensetzungen und Struktur der Basaltgesteine. 2 vols., Bonn, 1870.

†These statements are chiefly taken from volume vi of the Survey of the Fortieth Parallel, p. 259.

‡Neues Jahrbuch, 1875, p. 175. Compare also later citations of Verbeek and Fennema and of Behrens.

§ Survey of the Fortieth Parallel, vol. vi, p. 259, Microscopical Petrography. See also vol. ii, p. 236, Description of occurrence, by S. F. Emmons. Zirkel gives the essentials of its microscopic characters also in Berichte der Sächs. Gesellsch. der Wissenschaften, 1877, p. 238.

|| Denkschriften der Wiener Akad. der Wissenschaften, vol. xxxix, 1878, p. 40.

¶ Bijdrage tot de Kennis der javaansche Eruptief-gesteenten, Rotterdam, 1879, p. 247. See also Behrens, Neues Jahrbuch, vol. ii, 1883, p. 60, and Natuurk. Verh. Kon. Vet. Akad., Amsterdam, vol. xxiii, 1887.

**Die Vulkane der Capverden und ihre Produkte, Graz., 1882, p 19.

††Neues Jahrbuch, Beilage-Band. ii, 1882, p. 169.

‡‡Sitzungsberichte der Niederrheinische, Gesellsch. in Bonn, 1884, p. 98. See also regarding leucite from Choi, Steinecke, Jungere Eruptivgesteine aus Persien, Inaugural Dissertation, Halle, 1887.

§§ Tschermaks Mittheilungen, vol. vi, p. 160.

|||| Apuntos mineralogicos de la república oriental, An. Soc. Cient. Argent., vol. xvii, p. 49, sqq., Buenos-Ayres, 1884. The reference is on the authority of v. Chrustschoff as under 1890, later cited, the original not being accessible to J. F. K.

¶¶ Proc. Am. Assoc. Adv. of Science, vol. xxxiv, 1885, pub. 1886; Am. Jour. Sci., vol. xxxi, 1886, p. 74; analyses by Genth; microscopic examination by G. P. Merrill. The same occurrence was reported to Rosenbusch by H. Carvill Lewis, Mikroskop. Physiographie, 1887, p. 631. J. Francis Williams, Annual Rep. Ark. Geol. Survey, vol. ii, 1890, p. 267, and elsewhere in volume. Compare also subsequent references under Derby, Hussak, and v. Graeff.

Derby found it,* in 1887, in leucitite from the vicinity of Rio Janeiro, Brazil. For the leucite from Choi, Persia, described by Steinecke in 1887, see the reference above under Pohlig. In 1887 J. W. Judd † announced the discovery of leucite at Byrock mountain, in New South Wales, by T. W. Edgeworth David, who with W. Anderson described it in full in 1889. A boulder of leucite rock from Ishawooa canyon, Absaroka range, Wyoming, was described by Arnold Hague ‡ in 1889, since which date the rocks have been discovered in place and have been treated at length by J. P. Iddings under the name of leucite-absarokite. § In 1889, also, J. Shearson Hyland || detected leucite in a leucite-basanite from the volcano of Kiiima-Njaro in Africa, making the first announcement of it from the African mainland. In 1890 A. Lacroix ¶ made known its occurrence at Trebizond, Asia Minor, and in the same year v. Chrustschoff ** announced a new occurrence on the banks of the Tunguska river, in Siberia. In 1892, from some newly discovered material presented by J. F. Kemp to O. A. Derby, Hussak †† described a leucite-tephrite from New Jersey, although only alteration products were present in the specimen. The locality was later described in detail by Kemp, ‡‡ who in time identified actual leucite. Bäckström §§ reported leucite in 1896 from the Lipari islands. The greatest interest in connection with this present paper attaches to the work of Weed and Pirsson in the outlying ranges of the Rocky mountains in Montana. Leucite rocks have been met by them in the Bearpaw mountains, |||| and a very peculiar leucitic, plutonic rock called missourite has been described by them from the Highwood mountains.¶¶ Dr Hoffmann, of the Canadian Geological Survey, as cited by Weed and Pirsson, has reported leucite in boulders from the Horse-

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* Quarterly Journal of the Geological Society. August, 1887, p. 463. The determinations were made by Rosenbusch. Compare also O. A. Derby, idem, May, 1891, p. 261, and F. von Graeff, Neues Jahrbuch, vol. ii, 1887, 258, and E. Hussak, Idem, vol. i, 1890, p. 160, regarding pseudoleucites.

† Mineralogical Magazine, vol. vii, 1887, p. 190. Also T. W. Edgeworth David and W. Anderson, "The Leucite basalts of New South Wales," Records of the Geological Survey of New South Wales, vol. i, pt. 3, p. 153, Sydney, 1890.

‡ Am. Jour. Sci., vol. xxxviii, 1889, p. 47.

§ Journal of Geology, vol. iii, 1895, p. 938.

|| Tschermaks Mittheilungen, vol. x, 1889, p. 261.

¶ Comptes Rendus, vol. cx, 1890, p. 302. More fully described in the Bulletin de la Société geologique de France, (3), vol. xix, 1891, p. 737. M. Lacroix also announced probable leucite from Mont Doré, in France, in 1891, but the identification in not absolute, Comptes Rendus, vol. cxiii, 1891, p. 751.

** Bull. Imp. Acad. of Sciences, Saint Petersburg, vol. xxxiv, 1891, p. 225. Also in Neues Jahrbuch, vol. ii, 1891, p. 224.

†† Neues Jahrbuch, vol. ii, 1892, p. 153.

‡‡ Am. Jour. Sci., April, 1893, p. 298; May, 1894, p. 339.

§§ Geol. Fören. i Stockholm, Förhandl., vol. xviii, p. 155.

|||| Am. Jour. Sci., August, 1896, p. 143; Sept., 1896, p. 194. The latter reference refers to pseudoleucites.

¶¶ Am. Jour. Sci., Nov., 1896, p. 315.

fly mine, Cariboo district, British Columbia.* The writer has received from his friend, Professor F. C. Smith, of Rapid City, South Dakota, a suite of rocks from west of Terry peak, in the Black hills, which contains abundant leucites and which is now being studied for fuller description.

In résumé, it may be said that aside from the occurrences in Italy, Germany, and Bohemia, on the European mainland, leucite is known on the Lipari islands. In Asia it is found in Persia, Asia Minor, and

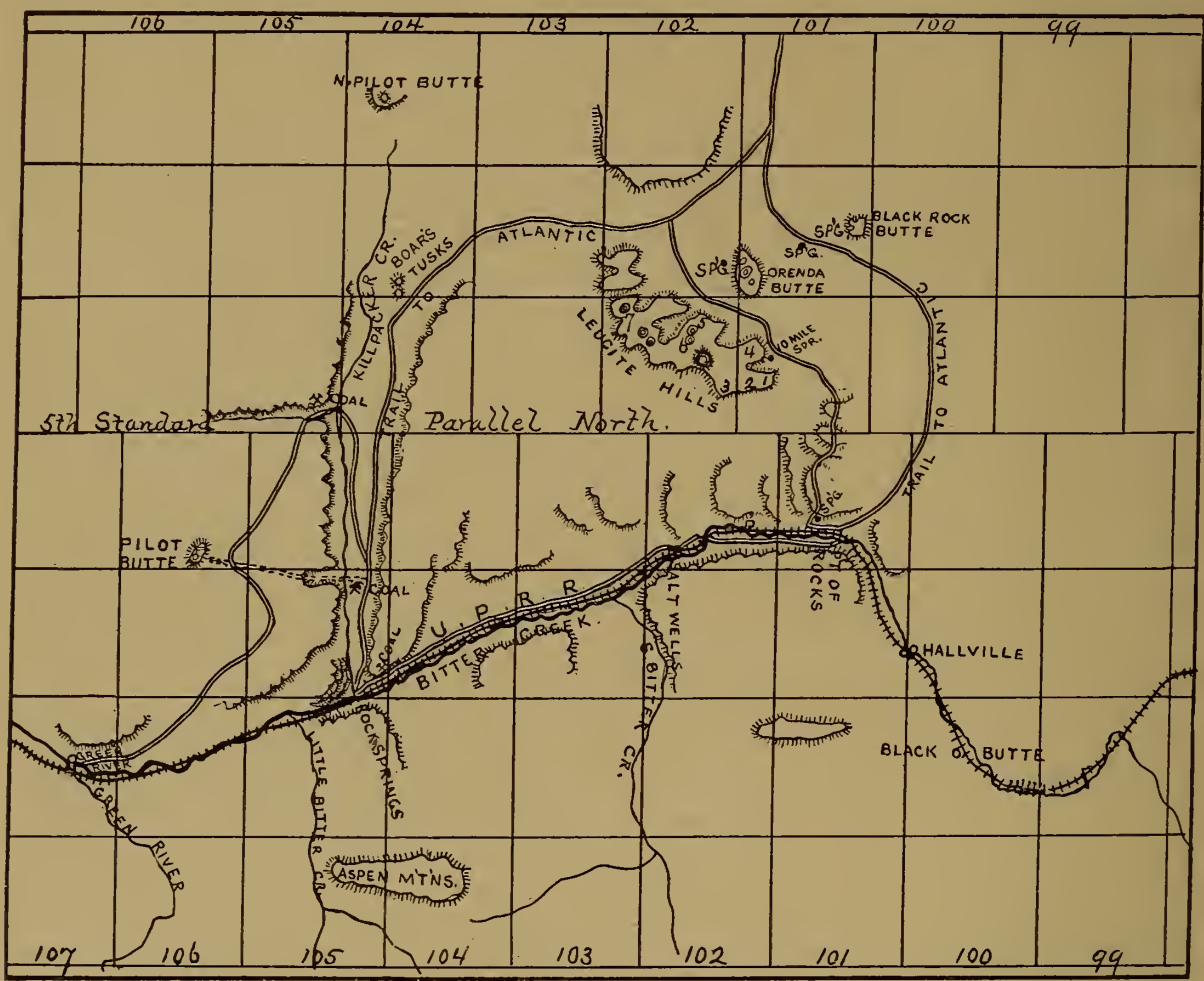

FIGURE I.—*Sketch-map of the Leucite Hills and Environs.*

It is based on map II of the Survey of the Fortieth Parallel and on the Land Office maps. The squares are townships, 6 miles on a side. The Leucite hills, Orenda butte, Black Rock butte, Pilot butte, the Boar's tusks, and probably North Pilot butte are igneous. The other escarpments, so far as known, are sedimentary strata.

Siberia, on the mainland; and in and near Java, of the East Indies. Off the coast of Africa it is met in the Cape Verde islands and on the mainland on Kilima-Njaro. It is known in one Australian locality. In South America it occurs in eastern Brazil and in Argentina. In North America it is known in Lower California, New Jersey, Arkansas, British Columbia, and in several places outlying from the eastern Rocky mountains.

* Geol. Survey of Canada, vol. vii, 1896, pt. R, p. 13.

The wide extent of these richly alkaline magmas along the eastern Rocky mountains is a most interesting phenomenon, and is rendered more so by the presence of phonolites in the Black hills, at Cripple Creek, Colorado, and in the Davis mountains, Texas, showing that eruptions of related rocks have occurred over a wide area.

Additional interest has attached to leucite in the past because it was so long regarded as a distinctively pre-Tertiary mineral and as fortifying the now abandoned view that Tertiary and later volcanics should be separated from earlier ones. Its remarkable mineralogical and crystallographical mimetic properties have likewise attracted to it special attention.

Geographical Location of the Leucite Hills.

The Leucite hills are situated in southwestern Wyoming, about 60 miles north of the Colorado line. They are within the drainage basin of Green river, from 10 to 15 miles north of Bitter creek, one of the eastern tributaries of Green river and the one which is followed by the Union Pacific railroad. The nearest station is Point of Rocks. from which a wagon road leads north past the hills to several mining camps in the Wind River mountains. The country is arid, with, however, several springs at intervals of 10 miles or less, and is on the western rim of the so-called Red desert. The accompanying sketch-map affords an idea of the location.

Previous Description of the Leucite Hills by S. F. Emmons.

Mr S. F. Emmons describes the Leucite hills as follows: *

"The Leucite hills consist of a number of little conical peaks protruded through the beds of the Laramie Cretaceous, which form the plateau country to the north of the railroad, near the Point of Rocks station. The form of some of these hills seems to indicate the outline of a former large crater, while to the north the lavas are spread out horizontally, capping the hills, and extend beyond the limits of our map, apparently forming the summit of North Pilot butte. Although no well defined Tertiary beds were found in actual contact with these eruptive rocks, it is evident, from their position directly over upturned Cretaceous sandstones and adjoining Green River beds, where the underlying, unconformable Vermillion Creek series is not seen, that they have been poured out not only since the deposition of the latter Tertiaries, but since their partial removal by erosion."

The observations of the writer corroborate this view of their late erup-

* Vol. ii of the Fortieth Parallel Survey, p. 236.

tion, because, so far as observed, float pieces are restricted to a zone, but one or two hundred yards broad, around the mesa itself. The Laramie sandstones on which the lava rests strike nearly east and west and dip from 10 to 15 degrees north. They are cream-colored sandstone with interbedded shales.

Additional Notes.

The leucite-rock forms several different and separated areas. The southerly one is much the largest, and extends about 10 miles, with its long axis running a little north of west. Its outline is irregular, so that it may be two miles wide in places and less than one mile in others. Its area is 10 or 12 square miles. About three miles to the north of its easterly end is Orenda butte, another flow of the lava, but of smaller area. It extends two or three miles in greatest length and varies from a maximum of two miles in width. Five miles northeast from Orenda butte is Black Rock butte, much smaller still. It is rectangular in outline, with reëntrant coves on the northwest and northeast, and is perhaps a quarter of a mile on a side. The sides are precipitous and the top is almost inaccessible.

Some 10 miles west of the west end of the Leucite hills proper, meaning by this the large south flow, are two small buttes in the valley of Killpacker creek, called the Boar's tusks, from which no material was obtained. Some 15 miles northwest of them and on the plateau west of Killpacker creek is Pilot butte, a small area of igneous rock, of which more will be said later on. It is about 1,500 feet from north to south and from 800 to 900 feet from east to west. North again from the Boar's tusks, a distance of about 10 miles, is North Pilot butte, presumably igneous, but from which no specimens were obtained.

Geological Characters.

Each of these buttes or mesas consists of a more or less dissected lava sheet, or aggregate of sheets, which presents an abrupt wall from 50 to 150 feet high, dependent on locality, and which is in the smaller buttes only accessible at one or two points. From the upper surface of Orenda butte and of the large south mesa arise cones of varying sizes, the apex of the largest being about 300 feet above the general surface. The others are smaller, some being quite low. They give the impression of craters from a distance, but all are solid, and they were evidently produced in the later stages of eruption by the welling up of a viscous lava,

FIGURE 1.—VIEW LOOKING NORTH FROM EAST END OF SOUTHERN MESA

Orenda butte and its cones on left; Black Rock butte on extreme right; immediate foreground is southern lava sheet, and the interval is Laramie sandstone

FIGURE 2.—VIEW OF LARGEST CONE ON SOUTHERN MESA, LOOKING WEST

The cone is about 300 feet high and was about 2 miles from the camera

FIGURE 3.—ESCARPMENT AT EAST END OF LEUCITE HILLS

Showing lava sheet and talus. Lava sheet from 50 to 75 feet thick

LEUCITE HILLS OF WYOMING

which did not flow far from its source. They doubtless indicate the location of the vents which supplied the earlier flows, as well. On the large, south mesa there are six cones, four of which are in pairs, while the other two are single. On Orenda butte there are one large and two or three smaller cones. Black Rock butte shows no cone, and Pilot butte has but a slight eminence or blister at its southern end.

These volcanic hills are therefore intermediate in type between the flat mesas such as the Table mountains, near Golden, Colorado, and the plugs of the Black hills.* They have the flat sheet protecting the underlying sedimentaries, as in the former, and in the cones show the forms assumed by viscous upwellings, not, however, confined in dikes or columns nor brought out into relief, in the cases cited, by the removal of surrounding walls of sedimentaries, as in the outlying igneous buttes about the Black hills.

The Leucite hills are surface flows. No dikes have been met about them, nor are tuffs present in any case known to the writer. The rock is often, if not almost always, of pronounced cellular character, produced beyond question by expanding steam in a surface flow; but even this in the material collected by the writer hardly reaches the pumice stage. The observed phenomena seem to have been produced by the outpouring and lateral spread of a highly fluid lava in the early stages, followed in the later ones by a similar viscous extrusion which remained quite near the vent.

Petrography.

Introductory.

There is considerable variation in the rocks gathered at different parts of the south mesa, and also between them and the others collected to the north. Some of the former are extremely rich in leucite and correspond to the rock described by Zirkel. Others, and increasingly so to the north, are poor in this mineral; almost, if not quite, to its disappearance, while orthoclase (sanidine) appears in larger and larger amounts. Haüyne is also present in relatively large anhedra, and, as later described, fairly large phenocrysts of augite and olivine are found in material from Black Rock butte. These phenocrysts are clearly visible to the eye, and by the microscope are shown to be surrounded by rims of biotite. Inclusions of sandstone and impure limestone are very abundant and are met in all parts of the flows as studied. The rock from Pilot butte is almost lacking in leucite, but while its biotite and augite are

* I. C. Russell: On the Nature of Igneous Intrusions, Journal of Geology, vol. iv, pp. 23 and 176.

practically the same as those of the more eastern flows, it has an isotropic groundmass which is apparently glass.

PREVIOUS OBSERVATIONS BY ZIRKEL.

The descriptions by Professor Zirkel were based on several specimens gathered by Mr S. F. Emmons in the necessarily hurried reconnoissance of the great area covered by the geologists of the Survey of the Fortieth Parallel. They came, as the writer is informed by Mr Emmons, from the large south mesa, and yielded to Professor Zirkel the following results: *

"They have a light yellowish gray, felsitic-looking, and very finely porous mass, in which the only macroscopical inclusion is some brownish yellow and reddish brown mica. This mica is not in six-sided or rounded plates, but in the form of remarkably long stripes and dashes, such as have seldom been observed. No other ingredients are visible to the naked eye, and the specimens do not disclose their rich secretions of leucite. At the first glimpse of the rock under the microscope the leucite appears, with its innumerable, very sharply outlined, colorless octagonal sections, .035 millimeter in diameter. None of the European rocks are as rich in leucite as these, and there is scarcely one in which the forms of the sections are so regular and so similar. As is the rule with all such small bodies, the sections are entirely dark between crossed nicols. . . . All of these leucite sections include quite pale green augite grains. . . . [The inclusions are described in detail.] . . . There are mixed with the leucites in this rock, as independent ingredients, pale green prisms, acicular needles, and microlites, which surely belong to augite, although their shape is indistinct, and larger, better crystallized individuals do not occur. In this fine aggregation and intermixture of leucite and augite the large biotite stripes are imbedded, and none of them of microscopical size was observed. This curiously colored mica, which resembles ormolu and whose long, thin streaks appear in surprising distinctness in the light rock mass, is remarkable for its comparatively very feeble absorption. . . . These plates seem for the most part to be scattered through the rock with some measure of parallelism, and hence the sections prepared parallel to the rock cleavage show no transverse sections of mica, but only basal ones. There is no trace of monoclinic or striated feldspar, and hornblende, olivine, mellilite, haüyne, and nosean are wanting. A small quantity of magnetite is present, and also a considerable number of comparatively thick apatites. . . . Occasionally indistinct colorless rectangular or oblong bodies appear, which possibly belong to nepheline. No corresponding hexagons are visible; but in any case this mineral must be relatively very rare. Some brownish black opaque microlites occur at intervals, and a few of them are included in the mica.

"The external aspect and the mineralogical composition of these rocks differ not a little from the other leucite-bearing masses. Their unusual light-gray color is produced by the extraordinary abundance of leucite and their comparative

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* Microscopical Petrography, p. 260.

poorness in augite. Moreover, the augite occurs only microscopically. The European leucite rocks commonly bear thicker individuals of augite, and much more of it, and also more magnetite, so that their color is a great deal darker. The entire absence of feldspar is as remarkable as the abundance of large macroscopical biotites."

This extended quotation is made to avoid repeating many details already published and to bring out the bearings of the later and more extended observations. Professor Zirkel also gives a good colored plate of a micro-section * and several drawings of individual leucites.†

UNPUBLISHED OBSERVATIONS OF CROSS.

After the specimens and observations for the present paper were gathered and fairly well worked up, the writer learned that his friend, Dr Whitman Cross, had visited the Leucite hills twelve years ago, and had made extended observations, amplified later by chemical analyses of the rocks, with the intention of some time publishing them. On consultation over the rocks it was evident that in general our observations are in harmony, but that each of us in important points had complemented the work of the other. The writer has sought, therefore, to leave untouched certain topics, such as the relations of the several flows, the chemical composition except as it is shown by the analyses already published, and, aside from one small sandstone fragment, the matter of inclusions or xenoliths, as Sollas uses the term, for on all these points Dr Cross' investigations are much more complete than my own, and their early publication will be looked for with great interest.

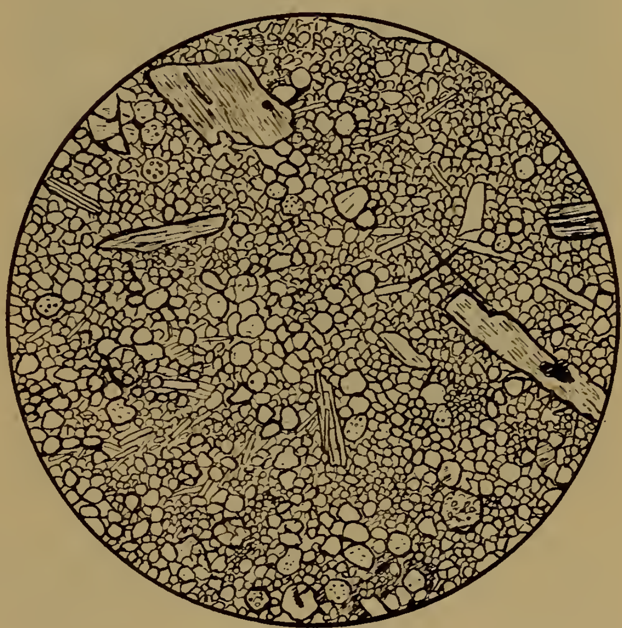


FIGURE 2.—*Drawing from a Photomicrograph of a Variety of Rock rich in Leucite.*

The large irregular crystals are biotite. The small rods are augite. The round crystals are leucite. The actual field was 1.2 millimeters. The specimen came from the west end of the Leucite hills, at locality number 7.

VARIETY OF ROCK RICH IN LEUCITE.

The specimens richest in leucite of those gathered came from the west

* Plate v, figure 4.
† Plate i, figures 21, 22, 23.

end of the south mesa, at locality number 7, as shown on the map (figure 1). The leucites are also the largest, and are illustrated in figure 2, which is simply a reproduction of an inked-in photomicrograph.* There is hardly any other mineral except the leucite and biotite in the slide. A little apatite, a rare needle of augite, and a grain or two of magnetite are the only ones recognizable. All the other slides from the Leucite hills have more or less sanidine.

VARIETIES OF ROCK WITH MORE OR LESS SANIDINE.

From the variety rich in leucite referred to above a series may be established through those with more and more sanidine, until at the extreme leucite is quite rare. In the intermediate varieties the leucites tend to be aggregated in swarms of minute crystals, while the sanidine makes up the chief portion of the remainder of the rock. The sanidine in ordinary light sometimes resembles a clear colorless glass, occurring as it does in the very cellular varieties, but the moment the upper nicol is put on its true character is evident. It has an extinction on its long side up to 8 or 10 degrees, and is occasionally once-twinned, although twinning is uncommon. The sanidine contains a network of minute augite needles which cross one another in every direction, and when it is well crystallized it has the form of rather stout rectangular rods.

FIGURE 3.—*Augite Phenocryst with Rim of Biotite, from Black Rock Butte.*

The actual field is 2.5 millimeters. The groundmass is a dense aggregate of sanidine, leucite, and augite, but no attempt has been made to differentiate them. The white spaces are holes, either amygdaloidal or produced in grinding.

An isotropic mineral is also present in one or two of the slides and in anhedra up to a millimeter in cross-section. This is undoubtedly haüyne,

* Figures 2 and 3 have been prepared by a method which combines the fidelity of a photograph with the distinctness of a drawing. Photomicrographs of rock sections are seldom of much significance. A negative was taken immediately from the eyepiece by a vertical camera. A blue print was made from this and inked in with water-proof ink. The blue color was then bleached out with a soda or ammonia solution, the print was washed, and the tendency to turn brown was neutralized by immersion in very dilute hydrochloric acid. In this way a line drawing, black on white, is afforded suitable for photoengraving, and much more quickly, accurately, and easily prepared than with a camera-lucida.

for microchemical tests of it with hydrochloric acid yield but few cubes of sodium chloride.

In specimens from the south mesa, the augite shows occasionally a tendency to develop larger crystals than the minute rods and needles in the groundmass. One was noted of perhaps 0.5 of a millimeter in diameter, but in Black Rock butte the large augites are more frequent and may reach 2 millimeters. They are colorless and are surrounded by a rim of biotite crystals as is shown in figure 3. Olivine is also met less commonly forming the interior core. In one or two slides an opaque decomposition product was noted, apparently limonite in largest part, that in one case had some unaltered strongly pleochroic strips still remaining. It corresponded in pleochroism to biotite or hornblende, but the dark color and almost opaque character prevented its sharp determination. If biotite, it must be of a different kind from the common light brown variety, which is perfectly unaltered. The light brown biotite, which is the most widespread and uniformly present mineral, has been quite fully described by Zirkel. Hexagonal plates do, however, appear in sections taken parallel to the flow, and exhibit a marked biaxial character.

The amygdaloidal cavities are almost invariably empty. In only two cases were fillings detected, and in each they were chalcedonic silica. Although often rusty and more or less weathered the rocks show surprisingly few secondary minerals of this character.

INCLUSIONS.

As stated above, inclusions of foreign rock, especially sandstone, are common. In thin section the biotite flakes eddy around them and produce very pretty flow-lines and similar phenomena. An inclusion of orthoclase was also noted, showing strongly undulatory polarization apparently from strains. In the specimens studied practically no contact effects were observable.

PETROGRAPHY OF PILOT BUTTE.

Fresh specimens from Pilot butte are not readily obtainable, and are in most cases seamed with veinlets of secondary minerals. The rock has a dense, massive texture, gray in the least altered specimens, and giving to the unaided eye but slight clue to its composition. It is a difficult one to make transparent in thin sections, and of these only the outer edges are, as a rule, available for fine determinations. The light brown mica of the Leucite hills is present in considerable amount, but augite is much more in evidence and is the predominating mineral in the rock.

It forms small, stocky rods in the groundmass and larger micro-phenocrysts up to one millimeter in length and .25 of a millimeter in diameter. It is colorless, often twinned on (100), and has the high extinctions of common augite. The felt of little rods makes up the chief part of the ground mass and exhibits flow phenomena of marked excellence. The biotite contains many little augites. Small, rounded leucites can be detected with high powers, but are in small amount. Much of the interstitial filling of the felt of augites is isotropic and homogeneous and is regarded as glass, although Pirsson's suggestive observations on the isotropic groundmasses of basic rocks makes one suspicious of the presence of analcite.* This, however, in lack of an analysis, does not impress one as a particularly basic rock. Its color is light and its whole macroscopic appearance suggests trachyte. It was described as trachyte by Mr Emmons,† but from the mineralogical details given by him it is clear that there must have been some confusion of slides, probably in the preparation of them. In its systematic relations the rock is mineralogically nearest the augitites, but it is clearly a variant from the group of rocks of the Leucite hills, with which, however, it has the mica and augite in common.

Chemical Composition.

The only analyses yet published are two, one made by R. W. Woodward with silica and the alkalies in duplicate, as given under I and its reference below, and the other by Pawel, made in Germany for Professor Zirkel. With it are placed several other analyses of western leucitic rocks.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2..........	54.32	56.30	54.04	52.91	51.93	46.51	47.28	52.11	55.11
Al_2O_3	13.37	12.63	20.27	19.49	20.29	11.86	11.56	23.01	16.07
Fe_2O_3.........	0.61	6.92	4.66	4.78	3.59	7.59	3.52	8.41	3.04
FeO..........	3.52	.....	0.64	2.05	1.20	4.39	5.71	1.75	8.46
CaO..........	4.38	5.63	2.75	2.47	1.65	7.41	9.20	3.40	6.46
MgO..........	6.37	5.08	0.16	0.29	0.22	4.73	13.17	2.18	3.10
K_2O.........	10.73	11.50	6.79	7.88	9.81	8.71	2.17	3.10	5.07
Na_2O.....	1.60	2.21	8.56	7.13	8.49	2.39	2.73	5.37	1.58
H_2O..........	2.76	.....	1.93	1.19	1.09	3.55	2.96	1.10	0.89
CO_2...........	1.82	.....	.....	none.	0.25	.....	.....	......	.....
	99.58	100.27	99.80	98.19‡	98.52‡	97.14‡	98.30‡	100.43‡	100.53
Sp. gr.........	2.22	.....	.....	.....	.....	.....	.....	2.838	2.546

* The Monchiquites or Analcite Group of Igneous Rocks, Journal of Geology, vol. iv, p. 679.

† Fortieth Parallel Survey Reports, vol. ii, p. 238.

‡ Additional components are given under the references which bring up the totals.

Localities and Authorities.

I. Rock from Leucite hills; R. W. Woodward, analyst. Fortieth Parallel Survey, vol. i; table opposite page 604, vol. ii, page 237. Duplicate determinations of the alkalies afforded Na_2O, 1.57; K_2O, 10.63.

II. Rock from Leucite hills; Pawel, analyst, for F. Zirkel. Sitzungsberichte der Sächsische Gesellschaft der Wissenschaften, Mathematische-Physikalische Classe, 1877, page 239.

III. Leucite-tinguaite, Magnet cove, Arkansas, R. N. Brackett, analyst, for J. F. Williams. Annual Report Arkansas Geological Survey, 1890, page 287. Dense rock.

IV. Leucite-tinguaite, Magnet cove, Arkansas; J. F. Williams, analyst. Idem. Rock with phenocrysts; contains also rare earths, 0.48; SrO, 0.09; MnO, 0.44; Li_2O, trace; Cl, 0.53; SO_3, 0.52.

V. Leucite-tinguaite, Bearpaw mountains, Montana; H. N. Stokes, analyst, for Weed and Pirsson. American Journal of Science, September, 1896, page 196. Contains also TiO_2, 0.20; Fl, 0.27; Cl, 0.70; SO_3, 0.67; P_2O_5, 0.06; SrO, 0.07; BaO, 0.09; Li_2O, trace.

VI. Leucitite, Bearpaw mountains, Montana; H. N. Stokes, analyst, for Weed and Pirsson. American Journal of Science, August, 1896, page 147. Contains also TiO_2, 0.83; Fl, trace; Cl, 0.04; SO_3, trace; P_2O_5, 0.80; CuO, strong trace; NiO, 0.04; CoO, strong trace; MnO, 0.22; BaO, 0.50; SrO, 0.16.

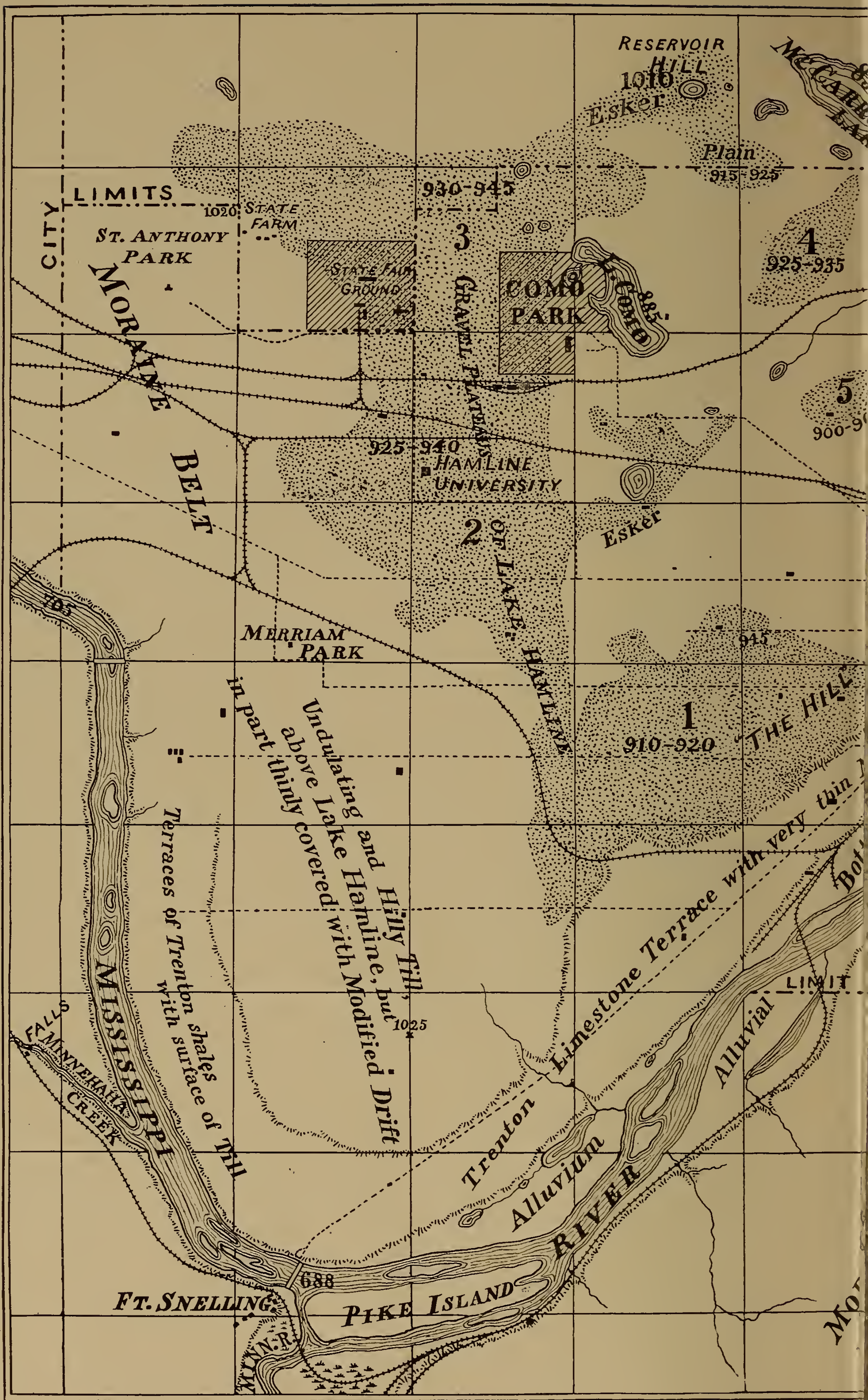
VII. Leucite-absarokite, Ishawooa canyon, Wyoming; J. E. Whitfield, analyst, for J. P. Iddings. Journal of Geology, vol. iii, 1895, page 938. Contains also TiO_2, 0.88; MnO, 0.13; P_2O_5, 0.59; Cl, 0.18.

VIII. Leucitophyr, Lower California, v. Chrustschoff. Tschermak's Mineralogische und Petrographische Mittheilungen, vol. vi, 1884, page 160. Contains also TiO_2, 0.15; P_2O_5, 0.19.

IX. Leucite rock, Montalto, Italy, Antonio Verri. Bolletino della Societa Geologica Italia, vol. vii, 1888, page 49. The analysis is taken from the Neues Jahrbuch., 1891, vol. i, page 271.

An examination of numbers I and II at once shows marked peculiarities. The range in silica is high for basaltic leucite rocks, of which VI and VII illustrate the usual values, although somewhat low. The alumina is low, the lime fairly high, and the magnesia remarkably high, exceeding the lime. The alkalies are high, and the great richness in potash as compared with soda is worthy of comment. It is clear from the analysis that a very exceptional rock would result from this magma. Number IX is the nearest parallel to it in general composition. The other analyses illustrate the ranges of the leucite rocks that have been thus far discovered in the west.

The rocks of the Leucite hills, it seems to the writer, are best described as leucite-phonolites which shade into leucitites or related rocks, by which name they have been usually called, as the result of Zirkel's earlier observations, and before the presence of sanidine was known. Zirkel himself merely places them with the leucitites in his recently published and invaluable Lehrbuch der Petrographie. The forthcoming paper of Dr Cross, elsewhere referred to, will doubtless settle their systematic relations by means of additional analyses.


RESERVOIR HILL
1010
Esker
Plain
915-925
930-945
CITY LIMITS
1020
STATE FARM
ST. ANTHONY PARK
MORAINE BELT
STATE FAIR GROUND
3
GRAVEL PLATEAUS
COMO PARK
L. COMO
885
4
925-935
5
900-9
925-940
HAMLINE UNIVERSITY
2
Esker
OF LAKE HAMLINE
705
MERRIAM PARK
945
1
910-920
THE HILL
Undulating and Hilly Till, above Lake Hamline, but in part thinly covered with Modified Drift
Terraces of Trenton shales with surface of Till
Limestone Terrace with very thin
1025
FALLS
MINNEHAHA CREEK
MISSISSIPPI
Trenton
Alluvium
Alluvial
LIMIT
RIVER
688
FT. SNELLING
PIKE ISLAND
MINN. R.

NT PAUL, MINNESOTA

MODIFIED DRIFT IN SAINT PAUL, MINNESOTA

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MODIFIED DRIFT IN SAINT PAUL, MINNESOTA

BY WARREN UPHAM

(Presented before the Society December 31, 1896)

CONTENTS

TOPOGRAPHIC FEATURES.

Saint Paul, comprising the southern third of Ramsey county, Minnesota, has a length of ten miles from east to west, a width of five to seven miles, and an area slightly exceeding 55 square miles. It lies on the north and east side of the Mississippi, excepting about five square miles which lie south or west of the river in the remarkable northward loop that here interrupts its general southeastward course. Reserve township and parts of Rose, New Canada, and McLean townships are united with the original city to give the present area as thus described. About half of this area remains in its former condition of fields, pastures, and woods, while the other half is occupied by the broadly extended city.*

The Mississippi river, where it begins to form the western boundary of Saint Paul, has an elevation, in its lowest and highest stages, of about 705 and 720 feet; four miles southward, at Fort Snelling and the mouth of the Minnesota river, its elevation is 688 to 710 feet; six miles thence northeast, at the union depot, 683 to 702 feet; and about five miles thence southeast, where it leaves the city limits, about 680 to 700 feet. The low-water stage of the river has thus a descent of 25 feet within and adjoining this city.

Northward from Fort Snelling the Mississippi occupies a postglacial gorge about a fifth of a mile wide between the crests of its bluffs, which are about 100 feet above the river, or 800 feet above the sea. The Minnesota river and the Mississippi river below the confluence of that stream, with their bottomlands, occupy a valley enclosed by rock bluffs from a half mile to two miles apart. Along the northwest side of the Mississippi from Fort Snelling to the capitol, a distance of six miles, the Trenton limestone, which forms the crest of the inner valley thus described, reaches back as a nearly level terrace from a quarter of a mile to one mile wide, at the height of 790 to about 800 feet above the sea, or a little more than 100 feet above the river. Very scanty deposits of glacial drift, or more generally of modified drift, remain on this rock terrace, their thickness varying from a few inches to a few feet.

From the river and its bottomlands, and from this terrace, the surface of the country ascends, by steep or by moderate slopes, to a general elevation of 900 to 950 feet above the sea. The greatest altitudes attained within the limits of the city are about 1,060 feet near its northeast corner; about 1,020 feet near its northwest corner, close to the State Farm and Agricultural College; and about 1,025 feet at a distance of one and a half miles north-northeast of Fort Snelling.

The larger part of the city has a moderately undulating or a knolly and hilly surface of glacial and modified drift, between 850 and 950 feet. Numerous plateaus of modified drift, gravel and sand, however, which are especially described in this paper, stretch with nearly level surfaces, 900 to 940 feet above the sea, along distances of one, two, or three miles. Indeed, by a narrow isthmus of the same plateau deposit joining its two largest areas, it is continuous five miles from south to north.

Rock Formations beneath the Drift.

The Saint Peter sandstone and the overlying Trenton limestone form

* In these studies of lake Hamline I have derived much aid from the good topographic maps called the Saint Paul and Minneapolis sheets, with contour lines at vertical intervals of 20 feet, which have been recently issued by the United States Geological Survey.

the bluffs of the river valley. The first 30 feet of the Trenton series is the mostly heavy-bedded and richly fossiliferous limestone which is worked by many quarries both in Saint Paul and Minneapolis. Shales, also containing abundant fossils, with occasional layers of limestone, from a few inches to a few feet thick, form the upward continuation of this series, and are exposed to an observed height of about 75 feet on each side of the river at a distance of one to two miles up the valley from the union depot. The maximum thickness of these shales known in the city of Saint Paul is revealed by their outcrop at the intersection of Carroll street with Dale and Kent streets, where they rise in a low ridge above the surrounding drift gravel and sand of the Summit Avenue plateau. At the house of Mr J. B. Chaney, on Rondo street, the highest part of this outcrop of shales, overlain by only one to two feet of glacial drift, reaches a height of 945 feet above the sea, or about 145 feet above their base in the neighboring valley bluffs.

The Trenton limestone extends with almost perfect horizontality from Saint Paul ten miles west to Minneapolis, and also southward to Fort Snelling, but toward the northeast, and also farther southward, this formation and the Saint Peter sandstone rise slightly, not more than a few feet to the mile, so that the underlying Shakopee or Lower Magnesian limestone comes into view in the bluffs of the Saint Croix, Mississippi, and Minnesota rivers, with still lower formations, as described by Professor N. H. Winchell, the state geologist, and by the present writer in the reports of the Minnesota Geological Survey.

Modified Drift of the Mississippi Valley.

Plains of drift gravel and sand border the Mississippi river, varying in height from 25 to 75 feet above the river and its scanty alluvial bottomlands, along nearly all its course from Brainerd southerly for more than a hundred miles to Minneapolis and Fort Snelling, often expanding on one or both sides of the river to a width of a mile or more. At Brainerd the plains are 1,200 to 1,210 feet above the sea; at Saint Cloud, 1,030 to 1,040 feet, and at Minneapolis 825 to 840 feet. They are thus seen to descend at nearly the same rate as the present river. Within the city limits of Saint Paul, however, the valley has only a very slight development of this declining glacial flood deposit.

Farther down the valley, at South Saint Paul, Newport, and Langdon, and onward to the south, similar beds again appear, with an elevation of 800 to 825 feet, in terraces on each side of the river. These modified drift deposits south of Saint Paul were doubtless formed as a flood-plain continuous across the valley; but they may have been partially eroded and removed by the river, cutting down its channel there nearly to its present level, before the deposition of the valley drift at Fort Snelling and northward.

Gradually, as the border of the ice-sheet receded, the avenues of drainage from its melting were occupied by modified drift, deposited progressively along the valleys, earliest at the south and later northward, as fast as the ice was melted back. The Late Glacial history of the vicinity of Saint Paul, however, which we learn from its plateau gravel and sand, leads me to think that the absence or extreme scantiness of modified drift in the valley from Fort Snelling to the southeastern limit of this city is due to lack of deposition there, rather than to removal by erosion.

Before the time of the glacial lake Hamline, in which the modified drift plateaus of Saint Paul were accumulated, the high level valley drift on the southeast had been mostly deposited. It was speedily and deeply channeled when the ice barrier holding that lake was melted through in the southeast part of the city of Saint Paul, opening this great valley to drain away the lake and to carry the waters of glacial melting and of rains from the basins of the Minnesota river and the upper Mississippi. Subsequently, while the ice-sheet was being melted away along the course of the Mississippi above Saint Paul, the valley drift of gravel and sand so amply developed in Minneapolis and northward was spread along this valley. This coarse stratified drift appears to have reached, however, only to the vicinity of Fort Snelling, and the same is true likewise of the terrace gravel and sand of the Minnesota valley, although much fine silt and clay were doubtless at the same time borne by the river floods past Saint Paul and far southward.

Plateaus of Modified Drift.

GENERAL CHARACTER.

The most remarkable feature in the glacial geology of the city of Saint Paul consists in its deposits of modified drift at high levels, forming a group of plateaus of gravel and sand, bordered by steep slopes which rise to nearly flat plains 100 to 125 feet above the highest terraces representing the old flood-plain of the river valley. These plateau deposits tell of a water level peculiar to this area.

Several districts of New England have similar modified drift plateaus which are found to record ancient water levels. In southeastern New Hampshire, twenty years ago, I examined and mapped for the geological survey of that state, under the direction of Professor C. H. Hitchcock, numerous plateaus of this class, which there were deposited by streams discharged from the retreating ice-sheet and flowing into the sea, that part of our eastern coast having stood during the Late Glacial or Champlain epoch from 100 to 200 feet lower than now, with gradual increase in the amount of the depression from south to north.* In Newton, Hingham, and other towns five to fifteen miles west, south, and southeast of Boston, such plateaus, well studied by Davis,† Gulliver, ‡ and Crosby and Grabau, § appear to represent a series of glacial lakes hemmed in between the land on the south and the retiring crenate ice-margin on the north, with outlets southeast and east to the sea, the relative heights of sea and land there in the Champlain epoch having been probably almost the same as now. More recently, Woodworth || has described somewhat similar modified drift deposits in the district of Narragansett bay, where they seem referable to deposition in fanlike slopes by the flooded and overloaded streams from the summer melting and rains on the contiguous receding ice-fields.

In Saint Paul the very nearly level expanses of these high tracts of gravel and sand imply a lacustrine origin; and the contour of the district, in connection with the courses of its moraine belts, implies that this was the site of a glacial or ice-dammed lake. The surface of the glacial lake during the early part of its existence was about 250 feet above the present river, or 930 to 940 feet above the present sealevel, these being the heights of the Hamline and Como plateaus. A little later, when the plateau crossed by Phalen avenue a mile east of lake Como was formed, the lake level had fallen apparently five or ten feet. At the time of formation of the Summit Avenue plateau, it had been further lowered several feet, having then apparently an elevation of about 915 feet. Another depression of some ten feet is recorded by the small plateau on which Western avenue intersects Lawson street. Belonging to a time intermediate between the last two, an esker and plateau, together nearly a mile long, were formed close north of East University avenue; but three very small plateaus which occur in a series extending thence a mile east and northeast, between Mississippi and Edgerton streets, were amassed by the continued action of the same glacial stream while the surface of the lake was falling more notably. At the time represented by the most eastern of these little plateaus, crossed by Whitall street, the lake had been reduced to an altitude of 870 or 875 feet.

These modified drift plateaus will be described in a numerical order corresponding with figures by which they are designated on the accompanying map (plate 15). The first three are connected with each other,

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* Geology of New Hampshire, vol. iii, 1878, pp. 155-164, 170, 171.

† W. M. Davis : Bulletin Geol. Soc. Am., vol. i, 1890, pp. 195-202.

‡ F. P. Gulliver : Journal of Geology, vol. i, 1893, pp. 803-812.

§ W. O. Crosby and A. W Grabau : Am. Geologist, vol. xvii, pp. 128-130, Feb., 1896.

|| J. B. Woodworth : Am. Geologist, vol. xviii, pp. 150-168, Sept., and p. 391, Dec., 1896.

and the union between the second and third is by a tract of gravel and sand a mile wide, with an undulating and rolling surface; but the fourth, fifth, and sixth, and the three little plateaus continuing eastward from the sixth, are isolated from each other, and in each instance are wholly surrounded by lower land.

1. SUMMIT AVENUE PLATEAU.

Most conspicuous among these plateaus is the most southern one, which is crossed by Summit avenue. It was formerly called Saint Anthony hill, because the road leading from the original village and steamboat landing in Saint Paul to Saint Anthony (now the east part of Minneapolis) passed over it. More commonly at the present day it is known simply as "the hill." Its extent as a high plain two miles long from east to west, with an average width of one mile, has become well built up with residences, chiefly during the last ten years.

From the Trenton limestone terrace on the south the steep ascent of this plateau is 110 to 125 feet, to the broad, nearly level plain, which varies in height from 910 to 920 feet, and in some places 925 to 928 feet, above the sea. The Trenton shales extend, in this southern ascent, 60 to 75 feet above the limestone, and are capped by about 50 feet of the modified drift. On the north the descent from the plateau is 75 to 25 feet, decreasing westward. On the west its level gravel and sand abut upon a slightly higher tract of moderately rolling and knolly till, which presents in some parts the characteristic topography of a marginal moraine.

The southern border of the western part of the plateau, at Ridgewood park, where the Chicago, Milwaukee and Saint Paul railway curves northwestward, has a thickness of about 100 feet of stratified gravel and sand. From this maximum, the thickness of the modified drift diminishes to its north central portion, where the underlying till in a few places extends up to the surface, while on Dale and Carroll streets, and for an eighth of a mile eastward, the Trenton shales, as before noted, outcrop in a low ridge 25 feet above the gravel plain.

2. HAMLINE PLATEAU.

Narrowly connected with the Summit Avenue plain by a tract of sand and gravel an eighth to a quarter of a mile wide, having the same height as the large plains on the east and north, the Hamline plateau or plain, 925 to 940 feet above the sea, thence extends two miles northward, with a width varying from one mile to nearly two miles. Along the east side of the connecting sand tract and of the wide Hamline plain, there is a descent from that plain of 25 to 40 feet, to smooth till areas thinly covered with modified drift, excepting near the middle of that side, where an esker or rather broadly rounded and in part flat-topped ridge of similar height as the plateau plain extends from it northeasterly to the House of the Good Shepherd and onward to the Calvary cemetery. On the west the Hamline plateau is likewise bordered by lower land of glacial drift or till, whose hollows descend 25 to 50 feet, with tracts of morainic hillocks that rise nearly to the same height as the modified drift plateau. Only on the southwest is this plateau, with the connecting sand tract that continues southward to the Summit Avenue plateau, bordered by slightly higher land, which is morainic till.

The depth of the Hamline gravel and sand, as shown by wells, is mostly from 30 to 50 feet. At Hamline University, which is near the center of this area, and thence northwestward, the surface is mostly sand, but other parts are interbedded sand and gravel. Here, as in all these plateaus, the gravel contains, in its coarser layers, pebbles and rounded cobbles up to six inches or sometimes a foot in diameter.

3. *COMO PLATEAU.*

Undulating or broadly ridged sand and gravel, occupying a width of a mile, with crests at the same elevation as the plains on the south and north and with depressions 10 to 30 feet lower, join the Hamline and Como plateaus. West and northwest of lake Como, within an eighth to a quarter of a mile from the lake, moderately and in part steeply ascending slopes of gravel and sand rise to a flat plain 45 to 60 feet above the lake, or 930 to 945 feet above the sea. This plateau or plain stretches nearly three miles from east to west, with a slight ascent northwestward, attaining an altitude of 960 feet on the northern part of the State Agricultural College farm. On the north it is bordered by slightly higher areas of till, more or less covered with undulating modified drift. Southwestward, in Saint Anthony Park and on the State farm, it is in part bounded by a narrow northwest to southeast moraine belt of till, which rises some 50 feet above the highest northwest part of the plain, and in part southward by depressions in the moraine which sink 40 to 50 feet below the southern and lowest part of this Como plateau.

The descending southward slope of the plain is due undoubtedly to the abundance of the supply of drift overloading the streams that flowed from the melting ice sheet, so that this deposit formed a wide flood-plain inclined 10 or 15 feet per mile. The adjoining ice-sheet on the east, north, and west confined the flooded streams and their modified drift, causing the northern part of the plain to lie probably 15 to 25 feet above the level of the glacial lake on the south.

The maximum depth of the Como gravel and sand deposit is at least

50 to 60 feet, this being the height of its steep ascent near the northwest end of lake Como, and of the slopes which descend from the plain to large bowl-shaped hollows that contain lakelets within a half mile north of the Como lake and park. In these hollows masses of ice remained after the contiguous parts of the ice-border had retreated, while the deposition of the stratified drift rapidly built up the enclosing plain.

4. *PLATEAU OF WESTERN AND PHALEN AVENUES.*

One to one and a half miles east of lake Como, after crossing an intermediate till area, Phalen avenue extends over a plateau of stratified gravel and sand, which reaches a mile from northeast to southwest, with a maximum width of nearly a half mile. Its height is 925 to 935 or 940 feet above the sea, the nearly flat expanse having a very gentle descent southwestward, amounting to about 10 feet in its length of a mile. The line of northern extension of Western avenue passes over its northeast part. On the northwest, this plateau is bordered by a depression 25 to 60 feet lower, declining northeasterly; and on the southeast it has a steep descent of 50 to 75 feet, to a morainic till area (in part thinly overspread with kame gravel and sand), which, varying in height from 850 to 950 feet, stretches four miles east to lake Phalen and White Bear avenue, with a higher but smooth area of till continuing farther east.

5. *PLATEAU OF WESTERN AVENUE AND LAWSON STREET.*

A small plateau of modified drift, about a half mile long, trending from east-northeast to west-southwest, and a third of a mile wide, is crossed by the most western half mile of Lawson street and by Western avenue. The Gorman school is situated on its southern verge. Its altitude is 900 to 905 feet, with the adjoining land on all sides 40 to 50 feet lower. The modified drift of this plateau is thus about 50 feet thick.

6. *PLATEAU NORTH OF EAST UNIVERSITY AVENUE.*

Considerable portions of this sand and gravel plateau have been removed in building Rice and Jackson streets and Pennsylvania and University avenues. The plateau reached continuously about a mile from west to east, before the large gaps were cut for these streets. Westward, it terminated in a narrow, esker-like, but level-topped ridge, trending to the northwest, while the main plateau trends east-northeastward. Its height is 905 to 915 feet, with a wide depression 50 feet lower on the north and a steep descent of 60 to 75 feet on the south. Its depth of stratified sand and gravel is 50 to 75 feet, lying on till.

Eastward, three outlying small plateaus of the same modified drift, each about a sixth of a mile long, decline in height, successively, to about

900 feet, 880 feet, and 875 feet. The most western, which is crossed by the southeast part of Pennsylvania avenue, was perhaps originally united with the next, from which it is divided by a creek and railroads in a gap nearly 100 feet deep. The most northeastern of these plateaus is crossed by Whitall street between De Soto and Edgerton streets.

Farther northeastward, between the last of these plateaus and lake Phalen, the moraine belt rises to about 900 and 920 feet, respectively, at the Cleveland and Harrison schools, where, as in all that eastern part of the city, little or no modified drift overlies the knolly and hilly till.

Eskers associated with the Plateaus.

No eskers were found, though they were carefully looked for, in the line of continuation from the plateaus last described, which, with the Summit avenue plateau, constitute a series four and a half miles long from west-southwest to east-northeast. Excepting the eskers already noted, connected with the east side of the Hamline plateau and with the west end of the sixth plateau, the only other gravel and sand ridge noted in or near the area of Saint Paul, such as can be referred to the class of eskers, is the prominent ridge extending a mile east-northeastward from the northeast part of the Como plateau. It seems to have been formed in the ice-walled channel of one of the chief streams which at the same time were depositing the Como plateau in a wider yet still ice-enclosed embayment melted out of the margin of the ice-sheet.

In its length of a mile this esker ridge, lying just outside the city boundary, rises gradually from about 950 feet to 1,010 feet, culminating, at its northeastern end, in the hill on whose top the reservoir of the Saint Paul water works is built, having its high-water line 1,003 feet and its surrounding grassed parapet 1,007 feet above the sea. The material of this ridge is almost entirely sand and gravel, with water-worn cobbles up to six or eight inches in diameter, and bearing on the surface very rare angular boulders one to two feet (and in one instance even four feet) in diameter. Steep slopes fall off about 75 feet to the north, east, and south.

At a distance of a third of a mile southward the esker gravel and sand merge into a similar deposit, which is spread as a flat plain, with its surface at 915 to 925 feet, extending a half mile from east to west, with a slight southward descent. A hollow about 40 feet deep divides this plain from the somewhat higher fourth plateau, which is close southeast.

Glacial Drift and Moraine Belts.

Professor N. H. Winchell and the present writer, in the Minnesota geological reports and in earlier papers, have discriminated the red till brought from the northeast, colored by its portions of sand and clay derived from the red sandstone and shales of the lake Superior region, and the blue (or near the surface yellowish gray) till, which is distinguished, among other features, by its boulders, gravel, and fine detritus of magnesian limestone brought from the extensive limestone areas of Manitoba, on and west of the Red river. These two glacial drift deposits meet along a somewhat devious line extending from the mouth of Rainy lake southward to Saint Paul. In this city the drift is mainly from the northeast, but this is thinly overlapped in the west part of the city by the northwestern drift. Under that yellowish and bluish limestone-bearing drift formation the northeastern drift continues, however, on this latitude, 10 to 20 miles farther west.

In the east part of Saint Paul a moraine belt of characteristically hilly and knobby till stretches from north to south, and on the southwest side of the Mississippi river it continues southward through West Saint Paul and Inver Grove. This moraine consists wholly of northeastern drift.

Another moraine extends through Saint Anthony Park and onward west of the Como, Hamline, and Summit Avenue plateaus of modified drift. Thence it crosses the Mississippi and continues south-southeast through Mendota, Eagan, and the southwest part of Inver Grove, into Rosemount township. Superficially, this moraine is northwestern till, with some overwash gravel and sand; but in its deeper part it consists, at least north from the Mississippi river, of northeastern till. West of Inver Grove and Rosemount the northwestern drift is amassed in a very extensive belt of morainic hills, which are the united accumulations corresponding to five distinct moraine belts in southwestern Minnesota and northern and central Iowa. The features appear to me to justify the following interpretation.

Confluent Currents of the Ice-sheet.

Toward the line of junction of the northeastern and northwestern till the slopes of the surface of the ice-sheet and its drift-transporting currents converged. Where the latter till overlaps the former, as in the west part of Saint Paul, a glacial current which had passed southwestward was pushed back and its place was taken by a stronger invading current from the northwest. The line of confluence of the slopes of the ice-sheet, under its capricious melting and the attendant precipitation of rain and snow, was shifted here several or many miles from west to east.

Finally, when the continued melting of this portion of the ice-sheet laid bare the earliest postglacial land of Ramsey county, the ice on the east accumulated the eastern moraine, and that on the west formed the western moraine, at their respective margins.

Glacial Lake Hamline.

EXTENT AND DEPTH.

Between these moraine belts a glacial lake was formed, held in on the east by the ice filling and deeply covering the Mississippi valley in the southeastern part of this city and for a considerable distance southward. The length to which this lake grew is shown to have been at least ten miles from south to north, and its maximum width was six miles or more. Its depth, above the present bed of the Mississippi river was at first about 250 feet; but this was reduced, probably by changes of the places of outlet from the lake, as well as by erosion of its outlet channels, to about 185 feet when the latest of these plateaus was deposited.

No shorelines of this lake have been recognized giving anywhere its latest boundary after it ceased to be walled in by the ice on such parts of its border, but I believe that its beaches may be found, by careful search with leveling, on favorable gently sloping tracts of till south of the river. It is known, however, that this entire lacustrine area was comparatively small, never comprising, perhaps, more than twenty-five square miles, for its water level soon fell below the earlier plateau deposits. If the ice border on the west retreated across the area of Minneapolis, and to some undetermined distance up the Minnesota river valley, before the ice barrier on the southeast was removed, the lake may have attained a much larger area; but no plateau drift nor other evidences of such westward extension have been carefully observed. It will be very interesting to extend a field examination west and south of Minneapolis with this question especially in mind.

MODIFIED DRIFT PLATEAUS FORMED IN LAKE HAMLINE

While the first narrow avenue of glacial drainage extended northward, enclosed by ice walls at each side, across the area of Saint Paul, the Hamline and Como plateaus of modified drift were formed in this body of water, which therefore may be appropriately named *Lake Hamline.* Slightly later eastern tributaries of this lake deposited in the embayments at their mouths the fourth and fifth plateaus, in their order, as here described, and the series of the Summit Avenue, the sixth, and the smaller eastern plateaus.

OUTLETS TO RICH VALLEY.

At the time of deposition of the six principal modified drift plateaus the outlet of lake Hamline appears to have flowed across the first place in the high moraine belt of West Saint Paul and Inver Grove, where in its course from north to south that great moraine sinks sufficiently low. This was in or near the northwest quarter of section 7, in the northwest part of Inver Grove township, with discharge thence south through Rich Valley to the Mississippi.* When a slight recession of the ice on the west uncovered two lower passes to Rich Valley, of closely similar height and each on porous gravel and sand, one near Westcott station and the second (necessary to be crossed by the outlet after flowing over the former) two miles farther southeast, on the small plain in the northeast quarter of section 29, Inver Grove, just east of a church and cemetery, having in each case an approximate height of 880 feet above the sea, the last small eastern plateaus in Saint Paul, at about 880 and 875 feet, were amassed.

Englacial Transportation of the Drift.

The deposits of lake Hamline supply important evidence, as I think, of the englacial transportation and finally superglacial position of a large part of the drift at the melting away of the ice-sheet. The areas of the several tracts of modified drift described in this paper are approximately as follows:

	Square miles.
Summit Avenue plateau	2.0
Hamline plateau	1.8
Esker ridge extending northeast from the last, with modified drift in Calvary cemetery and westward	0.3
Rolling tract connecting the Hamline and Como plateaus	0.7
Como plateau	2.0
Esker extending northeast to the reservoir	0.4
Plain southeast of the Reservoir hill	0.2
Plateau of Western and Phalen avenues	0.3
Plateau of Western avenue and Lawson street	0.2
Plateau north of East University avenue	0.25
Three small plateaus northeast of the last	0.15
Total	8.3

Upon these combined areas, somewhat exceeding eight square miles, the average depth of the water-deposited gravel and sand doubtless exceeds 50 feet, and may be fully 75 feet. All this modified drift I think to have been brought by streams which had gathered it from the melting ice surface, where it had become exposed by ablation of the upper part of the ice-sheet, as the Malaspina glacier or ice-sheet in Alaska is

*N. H. Winchell: Geology of Minnesota, vol. ii, 1888, p. 90. Warren Upham: Bulletin of the Minnesota Academy of Natural Sciences, vol. iii, 1889, p. 56 (read May 8, 1883).

covered on its border by its formerly englacial drift. The converging streams from the melting ice-fields on the east, north, and northwest spread in these plateaus approximately a tenth of a cubic mile of gravel and sand. No traces of subglacial stream courses are found from which this modified drift could have been partly or wholly brought to its tracts of thick deposition in the glacial lake; but instead, in two places, east of the Hamline plateau and northeast of the Como plateau, eskers were deposited at and near the mouths of the ice-walled rivers descending from the drift-strewn surface of the attenuated and rapidly melting marginal part of the ice sheet.

It is thus indicated that much of the drift was transported in the lower part of the vast continental glacier, and that, when its final melting had reduced the thickness near the border to a few hundred feet, the ice there became drift-covered, like the Malaspina glacier. Because the ice-sheet and local glaciers of Greenland have recently been mainly increasing or remaining nearly stationary, instead of rapidly receding, as in Alaska, the englacial drift of Greenland fills only the lower third or half of the steep frontal ice-cliffs, 100 to 200 feet high. Nearly the same proportional height of transportation of englacial drift was probably the condition of the North American ice-sheet on its peripheral areas to a width of several hundred miles from the margin of its maximum extension. Above the city of Saint Paul the ice-sheet probably attained a maximum thickness of 2,000 feet or more, so that the upper limits of its englacial drift would have been not less than 600 to 1,000 feet above the land surface.

We may further remark, also, that the volume of the englacial drift on areas of confluent ice currents, as the belt before mentioned extending from Saint Paul northward across Minnesota, was much greater than on other areas. Exceptionally abundant deposits of modified drift characterize this belt throughout the state.

Lacustrine Modification of englacial Till.

Two other observations of results due to lake Hamline deserve brief mention in closing this paper. One is an imperfect stratification seen in the till. It is exposed to a depth of 20 to 25 feet, at an elevation of about 875 to 900 feet above the sea, in an excavation for the construction of a road on the slope rising southward from the Mississippi river, in the west part of section 13, Mendota. This exposure is a short distance east of a bridge spanning a deep ravine, and the locality is opposite to the southwest extremity of the Summit Avenue plateau, the width of the valley between being one and a half miles. The modification of the till I attribute to the action of the lake water in receiving it from a previously englacial and superglacial position in and upon the melting ice-sheet. It is an observation almost exactly like that made by me a year earlier in the drift section of the lake Erie shore in Cleveland, Ohio;* and here, as there, I conclude that the volume of the englacial drift is represented by the thickness of the obscurely bedded or laminated till.

Deflection of glacial Striæ toward Lake Hamline.

This is a second result of lake Hamline. Although the Trenton limestone is extensively exposed in Saint Paul along the bluffs of the Mississippi valley and on its terrace, these rock surfaces are almost everywhere so deeply affected by weathering that they retain no glacial striæ. Only at one locality, on the south side of the river where the bluff is ascended by Charlton street, a third of a mile east of the Smith Avenue or High bridge, I found glacial striation in several spots, at and near the west end of Isabel street, bearing south 10° to 25° east, with another and quite different course of striation, partly on the same surfaces and also on other spots, bearing north 65° to 75° west.

In each of these sets of striæ, which comprise the only courses observed, we have good evidence that the whole thickness of 10 to 12 feet of till which lies next above the striated Trenton limestone, forming the surface of this slope, was englacial. During the greater part of the late glaciation which brought this till from the northeast, the ice current here doubtless passed southwesterly. When the vicissitudes of the glacial melting and changed distribution of snowfall caused the ice from the northwest to push back that from the northeast on this belt of contending currents, the base of the deflected ice moved south-southeastward, here effacing all the earlier southwestward striation.

A little later, however, the melting of the ice on the area of lake Hamline again deflected the ice current here, this time almost reversing it and directing it toward the open lake area. The site of these striæ is opposite to the northeast end of the Summit Avenue plateau, the intervening valley being a mile wide.

In each instance of these deflections of the ice currents, the base of the ice-sheet, more or less filled with englacial drift, rested directly on the limestone which it striated. The till was then englacial and superglacial. It did not come to occupy its present position beneath the ice-sheet, but after the ice in which it was contained had melted away.

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*Bull. Geol. Soc. Am., vol. vii, 1896, p. 331.

GAY HEAD CLIFFS

From unpublished chart of United States Coast and Geodetic Survey made in 1888. Heavy black lines represent outcrops of Neocene (Miocene and Pliocene); parallel lines, outcrops of Pleistocene older than the last glacial epoch; remainder of the cliffs mainly Potomac with marine Cretaceous.

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UNCONFORMITIES OF MARTHAS VINEYARD AND OF BLOCK ISLAND*

BY J. B. WOODWORTH

(Read before the Society December 30, 1896)

CONTENTS

* Published with the permission of the Director of the U. S. Geological Survey.

Introduction.

Evidence of unconformity in the deposits of the island of Marthas Vineyard has been pointed out by Professor Shaler * in two papers, to which this may be regarded as a sequel. Having familiarized myself with the evidence on this island, I examined Block island with the view of determining the extent of these erosion phenomena and endeavored to apply the methods of Irving and Van Hise in the correlation of the terranes which the several unconformities divide. As the most complete exposure of strata in these two islands is that of the Gay Head cliffs, I have taken that as a standard.

Gay Head Section on Marthas Vineyard.

GAY HEAD CLIFFS.

The topography of the Gay Head cliffs is exhibited on the accompanying contoured map (plate 16), which I am able to present through the courtesy of the Superintendent of the United States Coast and Geodetic Survey. On this map are represented only the outcrops of the Miocene where they are ascertained to be in place, and the outcrop on the cliff of the more important thrust-planes. The numbers at the base of the cliff on the map correspond to the stations established in 1889 and recorded on the section published by Shaler as plate 9 of volume 1 of this Bulletin. For the general structure of the cliffs, see the cross-section as represented in figure 1, page 207.

The survey of the cliffs made in 1889 served to show that the Gay Head section was a sedimentary complex of marine, fresh-water, and probably glacio-aqueous formations, with a definite sequence, including unconformities, some of which are involved in folds and faults of one or more epochs. The principal advance then made was the determination by physical means of a stratigraphic succession which has met the requirements of paleontologic correlation on the basis of a fossil flora by David White and of Neocene faunas by Dr Dall. Additional work upon the cliffs done from time to time in the conduct of summer schools of Harvard University enable me to state more clearly the existence of un-

* N. S. Shaler: The Geology of Marthas Vineyard, 7th Annual Report of the U. S. Geological Survey. Washington, 1888, pp. 297-363.

N. S. Shaler: On the Cretaceous and Tertiary deposits of eastern Massachusetts, Bull. Geol. Soc. Am. New York, 1890, vol. i, pp. 443-452.

conformities, some of which were in doubt in 1889. These will be reviewed in the relation which they bear to underlying and overlying formations.

NON-MARINE PLANT-BEARING BEDS.

The lowest beds exposed above sealevel on Marthas Vineyard, so far as observation has yet determined, are lignitic and leaf-bearing clays, the island series of Professor Ward, held to be Lower Cretaceous on account of their fossil flora. In the legend accompanying the section of 1889 these beds were placed in the Cretaceous because they were recognized as underlying the marine Upper Cretaceous on Marthas Vineyard. At the same time David White published a description of the plants found in these beds and referred them to the Lower Cretaceous. They are the beds now referred by Marsh to the Jurassic on the ground that they are the stratigraphic equivalents of the Potomac in Maryland, in certain strata of which he finds bones of Dinosaurs of Jurassic type.

With the conclusions of the paleontologists, the geologist in this field can have no difference of opinion. The lignitic and leaf-bearing clays of Marthas Vineyard underlie the marine Upper Cretaceous. The beds are obviously newer than the Newark group of southern New England. It is simply a question whether the fossil contents of the Potomac group afford a means of close correlation with accepted Cretaceous and Jurassic sections. There are a few observations upon the relations of the Cretaceous beds at Gay Head which are pertinent to this problem.

UNCONFORMITY INFERRED BETWEEN NON-MARINE BEDS AND MARINE CRETACEOUS.

The plane of demarcation between the non-marine plant-bearing beds and the overlying marine sands and clays of Upper Cretaceous age on Marthas Vineyard has not been definitely traced. That such a surface exists with some signs of local unconformity, at least, is to be inferred from the existence of water-worn patches of the lignitic materials in the sands at Gay Head, which, though without marine fossils, are lithologically identical with the fossiliferous strata in Indian hill. Again, at Indian hill traces of the lignite are found in the matrix enclosing the marine fauna, showing that the plant-bearing series had been attacked in the invasion of their area by the sea. In general, where coarse, gravelly sands like those of the Upper Cretaceous succeed unconsolidated clays, it is to be expected that the strong currents which were able to bring coarse sediments to a given position upon the sea-floor were strong enough to remove the finer particles already laid down by weaker currents. An exception to this action arises where the coarse sediments invade a clay bottom in the form of a layer with a cross-bedded delta-like front, in which case only the surface of the advancing coarse layer is in touch with water moving swiftly enough to disturb the bottom. The occurrence of cross-bedding on a small scale in the coarse sands at several horizons of the Gay Head section below the Tertiary makes it probable that the marine erosion of the underlying fresh-water beds, though recognizable, was of no great depth. In the highly inclined position of the strata on Marthas Vineyard differences of dip in two unconformable series can hardly be detected or relied upon if occurring in any but the most pronounced manner.

The occurrence of leaves in nodules in this section is apparently due to the relation brought about between the leaf-bearing clays and the pyritiferous clays through the inversion of the beds. The nodules are found in those portions of the section where the lignites with iron sulphides and sulphate of lime overlie by folding or overthrusting the leaf-bearing beds. Thus, in the large anticline between stations 19 and 23 (see plate 16), nodules occur in the clays on the south of the central lignite band but not in the same stratum on the north. The downward percolation of the solidifying agents, derived from decomposition in the lignite bed, has evidently brought about this change since the Gay Head folding. This explanation is in agreement with the observation of Ward that south of the New England islands the leaves do not occur in nodules in regions where the Potomac beds are not overturned.

The thickness of the plant-bearing beds in the Gay Head section must be taken with due allowance for thinning and thickening in close folds and for overthrusts, as well as for the probable occurrence of the marine Cretaceous at the summit of the pre-Tertiary series. One hundred and fifty feet is probably in excess for the beds exposed above sealevel.

MARINE UPPER CRETACEOUS.

The marine Upper Cretaceous described by Shaler and Foerste is characterized by locally hardened bands of sands containing the molds of fossils. Where this cementation has not taken place fossils have not been observed. The beds in the Indian Hill district consist of sands varying from fine to coarse textures, but with scattered larger grains of quartz and abundant muscovite scales. The local development of similar beds above the leaf-bearing section in Gay Head cliffs makes it probable that the marine sands are there represented. Such beds everywhere appear stratigraphically beneath the Miocene beds.

MIOCENE.

Thickness, extent, and divisions.—The determination of the age of the Miocene terrane by Lyell, and later with more precision by Dall, affords still the most satisfactory plane of reference in the Gay Head section. The Miocene nowhere exceeds ten feet in thickness, and is usually, by reason of erosion, much less. In certain places the Miocene is entirely wanting. The Miocene ofMarthas Vineyard consists of two well characterized lithological members, and probably a third, if this does not belong to the Pliocene. The lowest of these is the "osseous conglomerate" of Edward Hitchcock, to which succeeds the foraminiferal or greensand bed. The third Tertiary member may be considered as Pliocene.

Osseous conglomerate.—This stratum, from 12 to 18 inches thick, exists as a definite layer in the Gay Head section only, and there only in a limited exposure, just north of the Devil's Den, between stations 33 and 35. Elsewhere, as in Nashaquitsa cliffs, on the south road, and in the Peaked Hill district, the bed is represented in the form of rounded boulders lying on the surface of the pre-Tertiary beds or in the base of the greensand, where that is present.

The inorganic detritus of the conglomerate is mainly nut-sized quartz pebbles, invariably white and well rounded. Black chert and chalcedonic pebbles form a noticeable element in the conglomerate, the former being often fossiliferous, with corals, segments of crinoid stems, graptolites, and sections of unidentified shells, the whole assemblage indicating, in the opinion of Mr Walcott, who has examined them for me, the Silurian age of the beds from which the pebbles were derived.

The suggestion of a barrier to the westward of the Potomac formation prior to the incursion of the Upper Cretaceous sea is helpful in accounting for these Silurian pebbles, there being as yet no evidence, as in similar discoveries in the Pleistocene of New Jersey, that the pebbles may have come from Silurian outcrops in the present land area of New England.

As yet no trace of these chert pebbles has been seen in the strata underlying the Miocene on this island. That they are remanié from some earlier coast-plain formation is probable, in view of the origin of the quartz pebbles in the osseous conglomerate.

Cetacean bones give the name "osseous" to this bed. These bones are mainly vertebræ, with angular fragments of jaws, ribs, paddles, and head-bones, without distinct indications of their having been buried in a matrix previous to their deposition in the osseous conglomerate. The porous and cellular structure of the bones would give frequent opportunities for the adherence of a matrix distinguishable from that of the osseous conglomerate had they been exposed to such materials.

How doubtful this negative evidence is, however, must be admitted when it is considered that fragments of lignite evidently derived from the marine erosion of the Potomac series is of common occurrence in the osseous conglomerate along with fragments of petrified wood, the latter showing the borings of teredo. Amber of a reddish yellow color was found by Mr F. N. Balch, a student in Harvard University, in the osseous conglomerate in a part of the bed where lignite fragments are of common occurrence. It also was evidently derived from the lignitic beds below. It remains to consider the bearing of these and a few other observations upon the relations of the Miocene to the underlying pre-Tertiary strata.

Unconformity of Miocene osseous conglomerate and underlying strata.—The failure to find any trace of the Eocene in the Gay Head section is of itself indication of a very widespread erosion interval between the Miocene and the Cretaceous. It is a question whether the Eocene was deposited in this field. There are no indubitable evidences of Eocene materials carried over into the Miocene or higher beds. To the eastward, at Highland light, on cape Cod, Crosby has reported the finding of drifted fragments with a fauna considered to be of Eocene age.

That the pre-Tertiary unconsolidated rocks were quite stripped off from southeastern Massachusetts by the beginning of the Miocene is shown by the mode of occurrence of beds of this age near Marshfield, where the greensand is in very close contact with the granitic and gneissic floor on which the Potomac beds beneath Marthas Vineyard in all probability rest. It is likely that it was in this invasion of the sea that the lignite fragments were introduced into the osseous conglomerate. All the circumstances of contact of this bed with the underlying series and its composition point to the downsinking of the land at the beginning of Miocene deposition.

Foraminiferal or greensand bed.—The foraminiferal bed is possibly of deeper water origin than any sediments known at other horizons in the section, for there is an almost complete absence of land waste above the basal portion of the formation. The bed varies in thickness from nothing to as much as ten feet. At base it is locally made up of the debris of the osseous conglomerate, including rolled fragments of that stratum. In its lower portion it is usually of a green color, due to the presence of glauconite, but the upper half of the bed is a rusty brown, from the alteration of the greensand by meteoric waters. This change evidently took place before the Gay Head diastrophe, otherwise the oxidized portion of the greensand would be now uppermost in the section where the beds are inverted instead of underneath the unaltered zone where overturning has taken place.

The casts of *Macoma lyelli* occur in the greensand bed in the attitude of growth. The crab, *Archæoplax signifera*, is mainly found in the lower portion of this stratum, between stations 13 and 19.

Unconformity between Miocene greensand and osseous conglomerate.—The change from the conditions controlling the deposition of the osseous conglomerate to those which permitted the accumulation of several feet of foraminiferal casts almost without mechanical waste from the land involves the exclusion of ordinary shore processes by a depression of the land moving the shoreline inward; by a depression of the sea-bottom to a depth beyond the reach of land sediments, or by the production of an offshore barrier, with a warm quiet water lagoon in which organic growth went on without admixture of sediments from the erosion of the sides of the channel. This last case is represented by the condition of things which exists in the straits between the Queensland shore and the Australian Great Barrier Reef. Here, with a lagoon from 20 to 30 miles wide on the north and from 50 to 70 on the south, with a depth of water varying from 10 to 25 fathoms on the north and increasing southward to as much as 40 and 60 fathoms, Jukes dredged on the sandy bottom "bagful after bagful of orbitoloides, which also often form the sand on the mainland and the islands."

There is a tendency to assume that the presence of foraminiferal beds indicates tolerably deep water, but I am informed by Mr Alexander Agassiz that this is by no means a necessary conclusion, since great quantities of these forms may be driven towards shore and there destroyed so as to form a stratum. The occurrence of disrupted fragments of the osseous conglomerate in the base of the greensand bed on Gay Head is presumptive evidence that there was a shallowing rather than a deepening of the water in the change from the conditions of the earlier to the later Miocence deposits in this section. That this change was more than local is shown by the same distribution of rolled fragments of the osseous conglomerate in the greensand beds in the southern part of Marthas Vineyard.

Professor William B. Clark has suggested to me, from the case of the New Jersey Miocene, that the Miocene greensand bed on Marthas Vineyard may owe its origin in part to the redeposition of Cretaceous greensand beds now wanting on the Massachusetts coast. In the absence of specific identifications of the forms in the Gay Head section, it is impossible at present to discuss this question. Mr F. J. H. Merrill has also advocated the secondary nature of the greensand bed.*

PLIOCENE.

The existence of Pliocene strata in the Gay Head section rests upon Dall's identification of fossils found in sands lying upon the greensand bed. Similar sands without known fossils occur to the southward in the cliffs between the Pleistocene and the identified Miocene. It is doubtful whether these sands are Miocene or Pliocene. For structural

* This Bulletin, vol. 1, 1888, p. 556.

reasons, it is perhaps probable that they are of Pliocene age. They indicate a return to the conditions preceding the greensand. Locally there are brownish clays on the same horizon, and south of the Devil's Den the beds are yellowish green, apparently from the presence of disseminated glauconite.

UNCONFORMITY INFERRED BETWEEN THE PLIOCENE AND MIOCENE GREENSAND BED.

In the southern part of the cliffs the greensand is entirely wanting and the Pliocene sands rest upon the pre-Tertiary series, with rolled masses of the osseous conglomerate at their base. This unconformity involving uplift after the deposition of the greensand, together with the Pliocene fossils in similar non-feldspathic sands in a neighboring point in the cliffs, constitutes the present evidence for the determination of age here offered.

PLEISTOCENE.

Comparison with older beds.—The distinguishing feature of the strata already described is the absence of all undecayed feldspathic sediment. There are no pebbles of granite or gneiss in the Gay Head section from the Potomac to the Pliocene, inclusive. Evidently during pre-Pleistocene time the contributions to the sea-floor or to the basins of sedimentation in this area were derived from inward portions of the coast-plain which had already been deeply decayed or from decomposed portions of the Paleozoic and older rocks of the pre-Potomac terrane. It is probable, however, that some of the arkose beds of the Potomac derived their clays in the form of grains of clastic feldspar sufficiently strong to withstand mechanical transportation, their present kaolinized condition having resulted from subsequent decay in place. Sharply contrasted with this lower series of strata are the beds of Pleistocene age, throughout which are abundant clastic materials of a feldspathic nature.

The reasons for holding the lowest of these beds to be of Pleistocene age are as follows:

1. There is a lithological homology which binds these beds into a series of which the morainal deposits on the surface of the island are but the newest member.

2. The derivation of the materials from the base to the glacial detritus of the last ice invasion is plainly from the area of old rocks on the north through a process of rapid mechanical erosion by an agent or agencies capable of forming and transporting boulders, as well as thick sheets of gravels and sands.

3. The section afforded by these deposits with their intercalated erosion intervals is comparable to the record of the Pleistocene of the

Atlantic slope south of New York, and fills a blank otherwise unrecorded in the geological history of the New England area.

These Pleistocene deposits may be divided into several horizons upon lithological and structural grounds.*

Lower boulder bed.—The lowest member of these Pleistocene strata is a rather discontinuous boulder bed, exposed at stations 28, 31, 32, 41, between 40 and 47, and again between 54 and 59 in the Gay Head cliffs, the principal features of which bed were described by Shaler in 1889.

A few points not observed in 1889 may be briefly mentioned here. At station 28 the boulder bed rests upon the Miocene as a distinct boulder patch with one large boulder, 8 feet long, 6 feet wide, and 3 feet thick, estimated to weigh four tons. This boulder has within the last two years slipped out of its original position. At station 31 there is a small patch of the boulder bed containing rolled masses of the osseous conglomerate along with boulders of diorite. At station 41, just south of the Devil's Den, the conglomerate bed is exposed in an anticline and again at the bottom of a syncline, both these structures being overturned. At the top of the cliff, the boulder bed is the usual conglomeration of granitite, diorite, and gneiss from the mainland, along with locally derived materials, such as fragments of the greensand. At station 44, as noted in Shaler's report, there was found in this bed a small boulder of peridotite from Iron Mine hill, in Cumberland, Rhode Island, 60 miles away in the direction of transportation of debris in the last glacial epoch.

Between stations 54 and 59 the conglomerate lies almost horizontally on the upturned and eroded edges of sands and clays of the Cretaceous series. That this relation is true unconformity and not due to overthrust at the time of the Gay Head diastrophe is shown by the abundant occurrence of pebbles of the Cretaceous sands and clays in the conglomerate, which is at this point thoroughly cemented by the oxide of iron.

Between stations 33 and 35, in the quadrangular fold east of the Devil's Den, the base of the Pleistocene is distinctly marked by the occurence of small scattered subangular boulders of granitite resting on the light green silicious sands, which have in this paper been referred to the Pliocene. These boulders are much decayed, so that the granitite breaks up readily under slight blows of the hammer.

The decay of the pebbles and gravels of this horizon and the cemen-

* A synopsis of this Pleistocene history has been presented in the Seventeenth Annual Report of the U. S. Geological Survey, pt. i, pp. 25–31.

tation of the mass by the oxide of iron is widespread. The small cup-like nodules of reddish color which abound in this formation and are sometimes found in the later glacial deposits owe their origin to the changes which have taken place in the Cretaceous pebbles involved in this early Pleistocene formation. The outside of these pebbles being more or less completely consolidated by the oxide of iron, when the beds are disturbed the nodules thus formed escape and the unconsolidated sand or clay of the interior runs out, leaving the hollow pebbles so common on the New England islands.

The origin of the beds is evidently to be found in some kind of ice action at the opening of the Pleistocence period. The section in the southern part of the Gay Head cliffs shows that the deposition of these boulders was preceded by some folding of the underlying Cretaceous series. In a later episode in the history of this section it will be shown that profound folding of the beds preceded another epoch of accumulation of thick deposits, probably of glacial origin. In so far the evidence is favorable to the hypothesis that the disturbances in the New England islands are due to successive advances of an ice-sheet upon the soft strata of the coast plain. Absolute proof that the deformation was accomplished by the thrust or displacement of the ice, is wanting, however, in that in both cases the dislocations took place before the deposition of the beds which, by their nature, point to a glacial or glaceo-aqueous origin.

Compound gravels and sands of the Sankaty epoch.—Succeeding the boulder bed, or overlying directly the Neocene and older strata where the boulder bed is wanting, is a group of gravels and sands of a granitic character, the fragments of which are often subangular. The nearest analogues of these gravels are to be found along those parts of the New England shore where waves and currents are handling over and depositing the waste cut from kames and sand-plains of the last glacial epoch. These sands attain a thickness of at least 25 feet on Gay Head, and are the uppermost beds involved in the principal folding over the island of Marthas Vineyard. For the reason that beds occupying a similar position with reference to the folding on the island of Marthas Vineyard carry the well known marine fauna at Sankaty head, the name *Sankaty* group has been proposed for this horizon.*

In the east portion of the Weyquosque or Nashaquitsa cliffs the same sands occur, carrying abundant water-worn Miocene fossils, including crab nodules, pebbles of cetacean bones, sharks' teeth, fossil sponges (?) (seaman's biscuit), and numerous small unidentified fish teeth.

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* Seventeenth Annual Report of the U. S. Geological Survey, pt. I, pp. 26, 27.

At several points where these sands have been folded or thrust under the lignitic series, as in the Gay Head section, they have become firm red sandstones, as at locality 28, 24, and again at 42.

Unconformity following the Gay Head diastrophe.—Diastrophism has been defined in the abstract as the folding and faulting of strata. The Gay Head diastrophe is a particular instance of folding and faulting. There was, as above noted, some folding before the deposition of the lower boulder bed, but the principal diastrophe on Marthas Vineyard took place after 25 or more feet of gravelly and sandy deposits had been laid down upon the marine beds of the coast-plain.

By the folding and uplift of this time the present island areas appear to have been brought above the marine limit. The tops of the folds were truncated, but the precise nature of the erosion is not well displayed

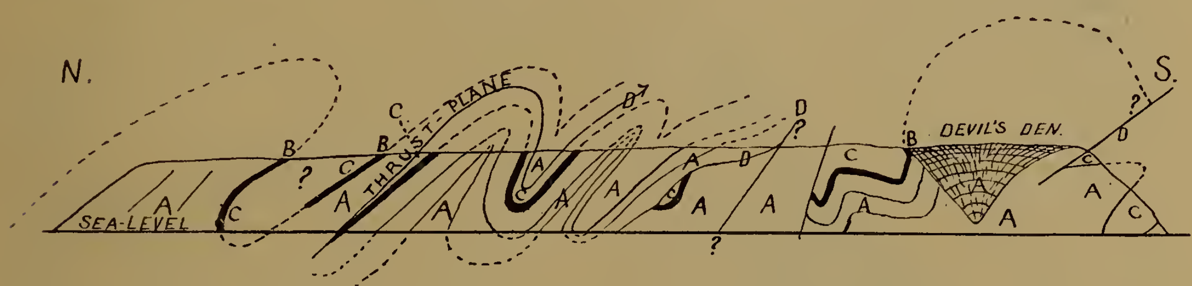

FIGURE I.—*Cross-section of Gay Head.*

Showing the attitude of the strata between the northwest and southwest points of the cliffs. *A*, Potomac and overlying Cretaceous strata; *B*, Neocene, mainly Miocene with the probable Pliocene; *C*, Boulder bed and Sankaty sands of Weyquosque or Lower Columbia age; *D*, Thrust-planes and faults. The morainal deposits which mantle the surface of the Head are omitted.

upon Marthas Vineyard. Westward on Block island, at Clay Head, the facts are more clearly shown (see page 210). It is evident, however, on Marthas Vineyard that the next succeeding deposits, those of the Tisbury beds, are separated from the folded series beneath by an unconformity.

Tisbury beds.—Along the north shore of Marthas Vineyard is a bench of clays and sands with scattered boulders disposed horizontally on the flanks of the highly inclined beds involved in the Gay Head diastrophe. These beds attain a thickness of about 150 feet above the present sealevel in the town of West Tisbury.

The beds are locally cemented by oxide of iron and are evidently older than the last glacial drift not only by reason of their greater ferrugination, but also by reason of their erosion and stratigraphic relations to the moraine. They are not well exposed at Gay Head.

Moraine of Marthas Vineyard and Block island.—This outer moraine of southern New England is composed on Marthas Vineyard of bouldery accumulations and gravelly till over the uplands of the island. In places on the highest parts of the island till is entirely wanting. In general the average thickness of the moraine is not greater than that of till upon the rocky uplands of the interior 100 miles back from the coast. The greater bulk of the materials deposited at this stage of the last ice invasion are in the glacial sand-plains forming the lowlands of southeastern Marthas Vineyard.

Unconformity between last glacial moraine and all older beds on the island.—The topography of the highlands of Marthas Vineyard, as pointed out by Shaler in 1888, is largely due to erosion before the last glacial invasion. Further study of this field shows that before the ice came upon the area

FIGURE 2.—*Sketch Map of the Island of Marthas Vineyard.*

Showing the topography of the highlands of folded Cretaceous, Neocene, and early Pleistocene strata mantled with morainal debris. The heavy dotted line represents the diverted drainage of the upper North Tisbury valley.

the streams had become adjusted to the structures formed by the Gay Head uplift and the subsequent mantle of Tisbury beds. Moreover, the stream occupying the northern valley opening upon the plains near the village of North Tisbury underwent beheading and capture at two points, where Roaring and Paint Mill brooks now escape through the northern ridge of the island down steep slopes into Vineyard sound. The morainal materials mantle over the erosion forms thus produced, showing conclusively that a long period of meteoric denudation intervened between the deposition of the Tisbury beds and the last ice advance (see map, figure 2).

This erosion epoch, which may be known as the Vineyard interval, corresponds to the long interglacial epoch which has been so often pointed out by various evidences outside of New England. It constitutes the last and the most marked unconformity by erosion on the island of Marthas Vineyard.

Extension of the Unconformities to Block Island.

AVAILABILITY OF UNCONFORMITIES IN DETERMINING HORIZONS.

The use of unconformities in correlating horizons is permissible in the New England islands, where in the Pleistocene series, fossils, even if found, are at their minimum value as determinants in questions of stratigraphic succession. Block island lies in the same geologic province as Marthas Vineyard and duplicates in every essential structural feature the geology of that island.

There is one case in alternating unconformity and deposition in which unconformity alone proves insufficient for the purpose of discriminating horizons—that is, where in an area adjoining the standard section, erosion at one of the epochs of unconformity has gone so far as entirely to remove the immediately preceding terrane, so that the number of unconformities separating terranes is not equal in the areas compared. In this case lithological characters or fossil contents must be relied upon to determine whether a given bed in the syncopated section represents all the time marked in the standard section by two horizons with an intermediate unconformity or whether it represents the first or second of the two beds thus separated. As a consequence of this removal of one formation in a series of alternating deposits and unconformities, the geologist is also left in doubt as to the extent of the denudation in the period of erosion preceding the deposition of the missing stratum, since the subsequent erosion may have cut deeply into the subjacent terrane. This is the problem presented at Clay Head, on Block island, in making a correlation of certain strata with the Gay Head section.

CLAY HEAD SECTION.

The geological structure of Block island is most clearly displayed at Clay Head. The structure at this point is the same in kind as that made out for Marthas Vineyard. The details are shown in the annexed cross-section (page 210, figure 3).

CRETACEOUS.

The beds commonly known as Cretaceous, on account of their fossil flora, are the lowest exposed on Block island. They appear at Clay Head, thrown into ill shaped and overturned anticlines and synclines, the compressed structure having a northerly dip. Nodules with impressions of leaves and fragments of sandstone carrying the marine Upper Cretaceous fauna occur as drift in the overlying Mohegan Bluff beds, pointing to the extension, at least in former times, of the Cretaceous beds north of the present site of Block island.

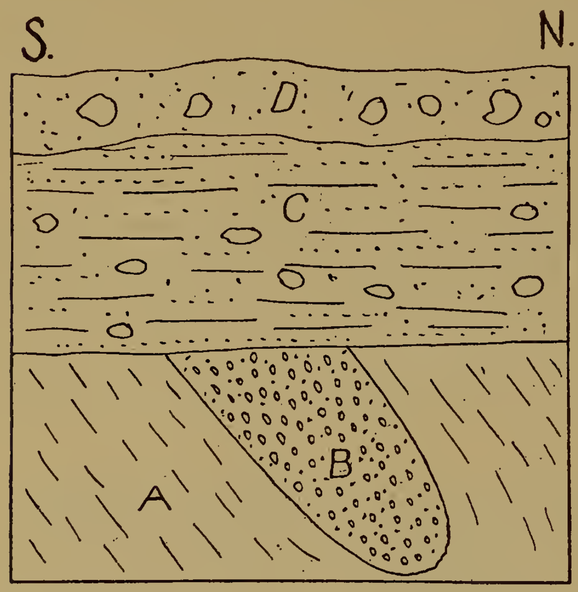

FIGURE 3.—*Section of a Portion of Clay Head, Block Island.*

Showing folding and unconformity of the time of the Gay Head diastrophe. *A*, Cretaceous clays (Potomac); *B*, Compound gravels and sands, equivalent to the Sankaty beds; *C*, Mohegan Bluff beds, equivalent to the Tisbury beds on Marthas Vineyard and probably upper Columbia; *D*, Last glacial drift, separated from *C* by unconformity, indicating a long erosion interval.

TERTIARY WANTING AT CLAY HEAD.

Neither the Eocene nor the Neocene have been identified in the Clay Head section or elsewhere on the island. The local erosion of the Miocene at Gay Head makes it probable that the Miocene, if not also the Pliocene beds, were originally laid down on this area but were removed either in late Pliocene or early Pleistocene time.

PLEISTOCENE.

The beds which on Marthas Vineyard form the lowest Pleistocene are represented in a fragmentary way on Block island. The gravels caught in the syncline at Clay Head are evidently Pleistocene for the reason that the sediments are compound and not simple silicious residues such as those which make up the Pliocene and older formations of the coast-plain. They rest here upon the Cretaceous and are evidently separated from them by an erosion unconformity. Structurally the beds occupy the place held at Gay Head by the Sankaty, the Pliocene, and the Miocene together. On lithological grounds alone does it at present seem possible to correlate them with the lowest Pleistocene, an identification which carries with it the inference that the Miocene and the Pliocene are wanting at Clay Head.

The lower boulder bed is probably represented at Clay Head by a mass of ferruginous conglomerate just south of the section shown in figure 3, but the stratigraphic relations of this mass are not clearly revealed.

GAY HEAD DIASTROPHE ON BLOCK ISLAND.

The pre-Pleistocene and the earliest Pleistocene on Block island present evidence of the same disturbance which at the close of Sankaty time profoundly inverted the coastal plain in the Marthas Vineyard area. At

Clay Head the beds were overturned as if by a push from the north, so as to give dips toward the mainland.

MOHEGAN BLUFF BEDS THE EQUIVALENT OF THE TISBURY BEDS.

Block island is thickly coated with a nearly horizontal group of sands and clays with boulders and cobbles, which rest on the truncated folds of the Clay Head section and bear upon their uneven eroded surface the moraine and sands of the last ice advance. These beds vary greatly in texture from point to point, and are equally varied in structure. They are typically exposed in the upper portion of Mohegan bluffs, where they rest on dark blue clays probably of the Cretaceous series. There is a lower bouldery clay, overlaid by gravels and sands, which are in turn succeeded by dark bluish clays carrying striated glacial boulders. The entire series is evidently of glacial origin, and is composed of some locally derived material at Clay Head, but more largely of debris from the mainland about the western margin of Narragansett bay.

LAST GLACIAL DRIFT.

The last glacial drift mantles Block island in the form of a moraine with local sand plains as near the center. It is a relatively thin deposit

FIGURE 4.—*Section in the Interior of Block Island.*
Showing last glacial drift resting on eroded members of the Mohegan Bluff series.

at Clay Head, and in the interior of the island is found at different elevations up to nearly 200 feet, resting on eroded sections of stratified sands and clays of the Mohegan Bluff series.

UNCONFORMITY BETWEEN LAST GLACIAL DRIFT AND EARLIER PLEISTOCENE BEDS.

The Mohegan Bluff beds where exposed are usually horizontal, but in the south side cliff foldings on a small scale are recognizable; but these dislocations do not account for the very different altitudes of the upper surface of the formation as it now exists. Standing upon the higher parts of Block island and looking down the slopes toward the sea, one can recognize the lines of a drainage system carved in the Mohegan Bluff beds, but now embarrassed by irregular accumulations of the last glacial drift. This is particularly true of the slopes descending from Beacon hill. This sculpturing marks the duration of the Vineyard interval on the island, and indicates here, as on Marthas Vineyard, that there was a long interval between the last and earlier Pleistocene formations.

Summary.

It remains to attempt the correlation of the local geologic features here described with the sequence of events made out for this region west and south of the New England islands. The work of David White, Hollick, Dall, and others leaves little doubt regarding the equivalence of the pre-Pleistocene members of the section. The earlier Pleistocene beds referred to in this paper, denominated Weyquesque by Shaler, have been referred to as Columbia by McGee. With the beds bearing this latter name south of the glacial region, the lower Boulder bed, the Sankaty and Tisbury beds appear to be equivalent; but in the district of the New England islands this formation is divisible into lower and upper members, separated from each other by a very marked unconformity, accompanied by the profound disturbance of the lower beds; hence the need of distinct local names such as Sankaty and Tisbury beds for the lower and upper divisions of the Columbia.

Furthermore, those who hold that the dislocation of strata along the line of these islands is due to the forward thrust of an ice-sheet must, it seems to me, admit that at the beginning and again before the close of this earlier series of Pleistocene deposits of Columbian or Weyquesque age, glacial thrust was exerted upon the Atlantic coast in this latitude, and this at times separated from the epoch of the superficial moraines of the islands by a very long interglacial epoch.

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SOLUTION OF SILICA UNDER ATMOSPHERIC CONDITIONS*

BY C. WILLARD HAYES

(*Read before the Society December 29, 1896*)

CONTENTS

SOLUBILITY OF SILICA UNDER OTHER THAN ATMOSPHERIC CONDITIONS.

It is well known that under conditions prevailing at considerable distances below the earth's surface silica is one of the more easily soluble of the substances entering into the composition of the earth's crust. This is shown by the formation of secondary quartz veins, the solution and redeposition of quartz in both sedimentary and crystalline rocks, and, on a large scale, in the replacement of silica by other minerals, as in the case of the iron ores of the Lake Superior region. It is also well known that during the process of rockweathering under atmospheric conditions, by the breaking down of various silicates, much silica passes into solution. Merrill † has shown that in the passage of various crys-

* Printed with the permission of the Director of the U. S. Geological Survey.

† G. P. Merrill: Weathering of micaceous gneiss in Albemarle county, Virginia. This volume, pp. 157–168.

talline rocks, as diabase and granite, from the fresh condition to that of soil, they suffer a larger absolute loss of silica than of any other constituent, the loss, however, being relatively greatest in those rocks which contain least free quartz.

Further, all river waters are known to contain more or less silica in solution, amounting in some cases, as the Saint Lawrence and Ottawa, to nearly a third of the total inorganic residue, but its presence is ordinarily attributed to the decomposition of silicates in crystalline rocks. While these facts are generally recognized, free silica is commonly regarded as the mineral least liable to be affected by solvents under ordinary atmospheric conditions, and a quartz pebble is expected to withstand all ordinary vicissitudes except the slow loss by mechanical attrition. It is doubtless true that, considered relatively to other rock-forming minerals, quartz is one of the most obdurate; but some recent observations show that under certain conditions now existing at the earth's surface free silica, quartz as well as its other forms, is by no means proof against chemical as well as mechanical agents of erosion.

Observed Cases of Solution of Silica under atmospheric Conditions.

SILICIOUS GEODES FROM SPURRIER, TENNESSEE.

The first to be described is that observed in the solution of silica in geodes collected by Messrs Campbell and Taff at Spurrier, Overton county, Tennessee. These silicious concretions occur rather abundantly in certain layers of the Carboniferous limestone, accumulating at the surface on the removal of the latter. They are of all sizes up to a foot or more in diameter, and generally have a rugose surface, somewhat resembling the bark of a tree. The outer portions are yellowish or white, and have an opaque, stony appearance, while the interior is colorless and translucent, resembling extremely fine grained quartzite or slightly granular vein quartz. Under the microscope this is seen to be made up largely of spherulitic aggregates of quartz, the elongated grains of quartz having a radial arrangement. There are also considerable areas of rather coarse, granular quartz, often with terminated crystals, but no cryptocrystalline or amorphous silica could be detected. Many of these geodes, as shown in plate 17, figure 2, are deeply etched upon one or both sides, not only the outer opaque shell being removed, but portions of the translucent interior. A part of this etching was probably accomplished by the solvent which removed the limestone, as one specimen at least was found embedded in the residual clay between two layers of limestone, evidently not far removed from its original position in the rock. In most cases, however, the solution was evidently effected after the geodes reached the

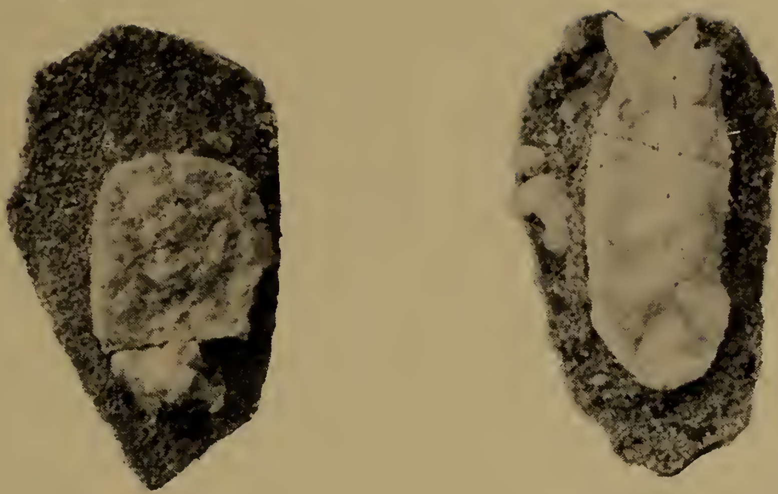

FIGURE 1.—ETCHED CONGLOMERATE PEBBLES FROM CLIFTY CREEK, WHITE CO., TENNESSEE (natural size)

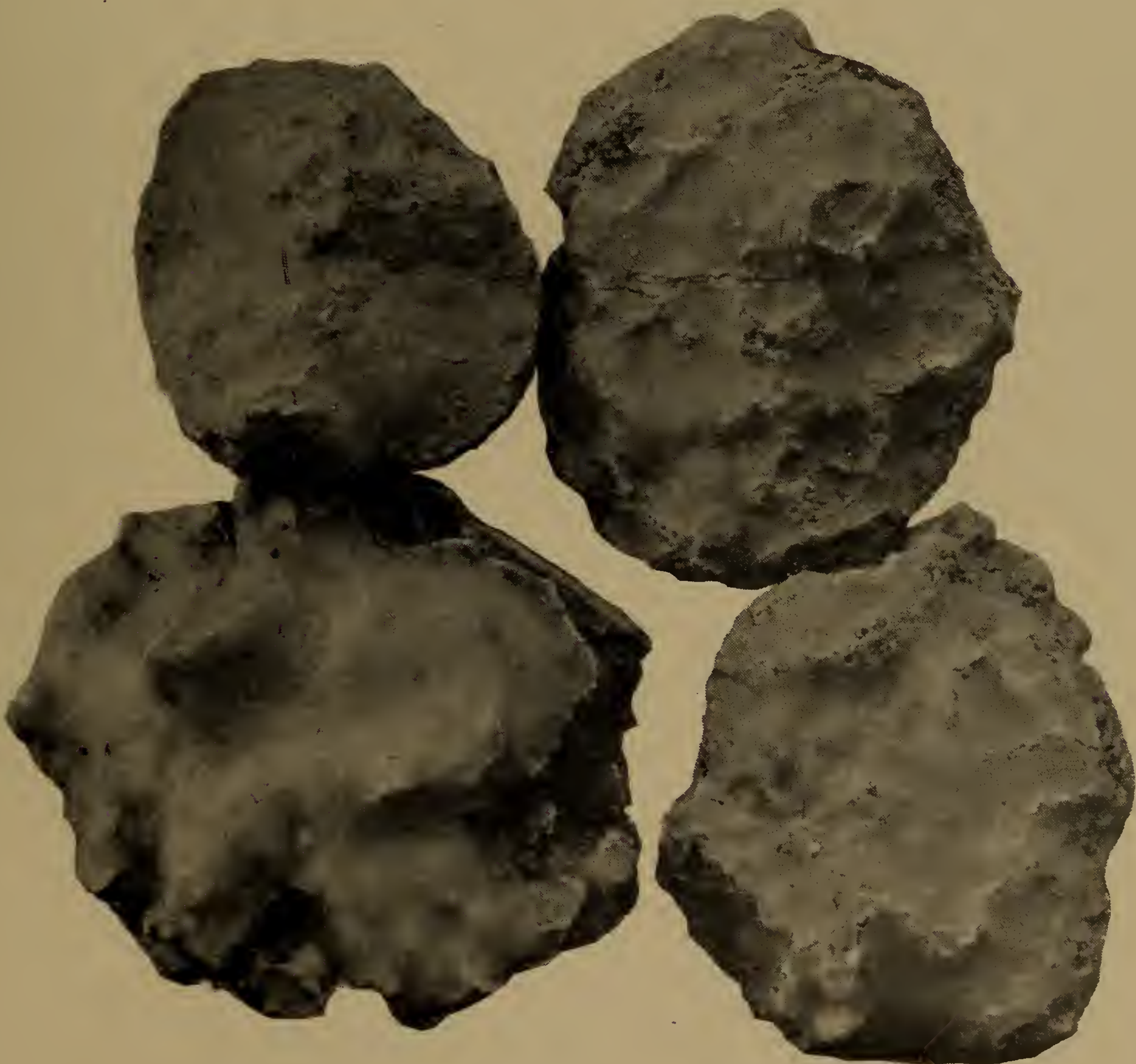

FIGURE 2.—ETCHED GEODES FROM SPURRIER, TENNESSEE (about ⅔ natural size)

ETCHED PEBBLES AND GEODES

ETCHED CONGLOMERATE PEBBLES FROM NUTTALL, WEST VIRGINIA

(about ⅔ natural size)

surface by the weathering of the enclosing rock, and is confined largely to their exposed upper sides.

From its microscopic structure, the silica of which these geodes are composed would appear to be but little more liable to solution than vein quartz or quartzite. Minute quantities of amorphous silica may, however, be present and by their solution facilitate the removal of the crystalline grains by solution or otherwise; hence less importance is attached to the solution of these geodes than to the etching of conglomerate pebbles composed of various forms of silica which has been observed at several rather widely separated points in the south.

ETCHED CONGLOMERATE FROM NUTTALL, WEST VIRGINIA.

The first case to be described is one observed by Mr Campbell at Nuttall, West Virginia. The conglomerate in question, which belongs to the coal measures, is composed of rather coarse quartz sand with slightly yellowish cement, in which are embedded well worn pebbles of white vein quartz. The latter vary in size up to three-quarters of an inch in diameter and are somewhat irregularly distributed. Ordinarily the pebbles, wholly unaltered, weather out by the chemical or mechanical disintegration of the sandy matrix. In the case observed, however, where the conglomerate receives the drip from an overhanging cliff, the projecting portions of the pebbles, as shown in plate 18, are deeply pitted, evidently by solution. Mechanical wear in the formation of these cavities is excluded by the form of the resulting surface. The latter is rough and irregular, quite unlike the smooth portions of the pebbles where still protected by the matrix. The outer portion of the pebbles is apparently less easily affected by the solvent than the interior and forms a sharp rim about the irregular cavities hollowed out within. In some cases a third of the pebble has thus been removed. The surface of the sandstone matrix in which the pebbles are embedded is also pitted, probably by the same process of solution, although such a surface might also be produced by mechanical means in case the cement were less indurated in some portions of the rock than in others. When the surface is closely examined with a glass both processes are seen to have contributed to the result. In some places the pitting has been produced by the solution of the sand grains which are smoothed off evenly, and in others by the removal of the cement, leaving the sand grains intact.

ETCHED CONGLOMERATE PEBBLES FROM WHITE COUNTY, TENNESSEE.

The second case observed is on Clifty creek, White county, Tennessee. The conglomerate, in this case also a member of the coal measures, forms the bottom of a small canyon and is covered by the creek at high water, but is uncovered throughout the greater part of the year. The matrix is a coarse, white sandstone which weathers yellow by the oxidation of the slightly ferruginous cement. Embedded in this are rather abundant pebbles varying in size, the largest being two inches in diameter, and composed chiefly of white vein quartz and fine grained vitreous quartzite, together with a few of chert. As shown in plate 17, figure 1, the projecting portions of these pebbles have been in part removed, although they still project somewhat above the enclosing matrix. As in case of the Nuttall conglomerate, the exterior portions of the pebbles are less easily affected than the interiors, and when the pebble has been a third or half removed the outer shell forms a rim, within which is a depression with a slight elevation in the center. The chert pebbles show less evidence of corrosion than those composed of quartz. Their upper surfaces are somewhat worn down and even slightly hollowed, but this might have been produced by mechanical means, which is not the case with the quartz. One of the chert pebbles is cut by a thin vein of white quartz evidently in place before the pebble was formed. The quartz in the vein has been removed somewhat below the surface of the enclosing chert, having apparently been more readily attacked by the solvent than the latter. However surprising this conclusion may be, it is supported by a comparison of numerous pebbles which appear to have been under essentially the same conditions. Those composed of white vein quartz were found generally to be most deeply etched, those composed of chert were least affected, while the quartzite pebbles appeared to occupy an intermediate position between the other two kinds.

ETCHED CONGLOMERATE FROM STARRS MOUNTAIN, TENNESSEE.

The third case observed is in a conglomerate of lower Cambrian age from Starrs mountain, Tennessee. The matrix is a coarse, feldspathic sandstone containing layers of well rounded pebbles, mostly quartz, with a few of some feldspar much altered. The former are between half an inch and an inch in diameter and the latter are somewhat larger. The projecting portions of the quartz pebbles on one side of the block shown in plate 19, are almost entirely removed and, as in the other cases, evidently by solution.

The accompanying diagram, figure 1, shows the form assumed by the majority of these pebbles as well as those at Clifty creek described above. Ordinarily a distinct rim projects above the matrix in which the pebbles are embedded. Within this is a depression, while a slight elevation occupies the center. The rim is sometimes absent, and the surface of the matrix is flush with that of the pebble. The etching is not confined to the larger pebbles, although it is there most noticeable,

ETCHED CONGLOMERATE PEBBLES FROM STARRS MOUNTAIN, TENNESSEE

(about ⅔ natural size)

for when examined with a lens the projecting portions of the sand grains, both large and small, are generally leveled off, forming with the kaolinized feldspathic matrix a more or less even mosaic.

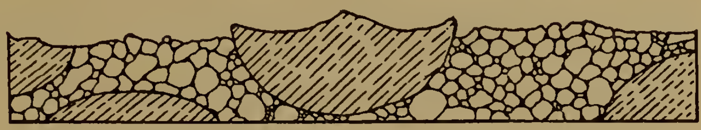

FIGURE 1.—*Section of Conglomerate showing etched Pebbles.*

The sectional view shown on the diagram suggests the form assumed by the faceted pebbles or glyptoliths described by Woodworth, Davis, and others* and by them ascribed to the action of wind-blown sand. The latter, however, display certain well marked characteristics, which sharply differentiate them from those above described. The sand-cut facets, even when most perfectly developed, are always slightly convex, or at least never deeply concave. They approximate plane surfaces which, in case several are present on the same pebble, intersect in more or less definite straight lines, and finally they are always more highly polished than other portions of the same pebble which display only the ordinary water-worn surfaces. All of these characteristics, and particularly the last, serve to distinguish the wind-carved surfaces from those produced by the corrosion of a solvent.

Analogous Cases of Solution of Silica.

ETCHED PEBBLES FROM COAL MEASURE CONGLOMERATE OF OHIO.

Some analogous cases of the solution of silica under atmospheric conditions, only a part of which have been personally observed by the writer, may be mentioned in this connection.

At the Cleveland meeting of the American Association in 1853 some specimens of the Ohio Carboniferous conglomerate were exhibited by Professor Brainerd,† in which the impressions of the stems of plants were as distinctly transmitted to the quartz as to the sand matrix. Professor Brainerd argued on the evidence afforded by those specimens that the pebbles were of concretionary origin, and that they had received the impressions while still in a gelatinous condition. Professor Newberry,‡ on the other hand, expressed the opinion that the pebbles had been dissolved away where they were in contact with the plant by means of the

* J. B. Woodworth: Post-Glacial Eolian Action in Southern New England, Am. Jour. Sci., vol. xlvii, 1894, pp. 63–71. W. M. Davis: Faceted Pebbles on Cape Cod, Proc. Bost. Soc. Nat. Hist., vol. xxvi, 1893, p. 166. Max Verworn: Sandschlieffe vom Djebel Nakus, Neues Jahrb., Bd. 1, hft. 3, 1896, pp. 200–210.

† Jehu Brainerd: Origin of the Pebbles Quartz of the Sandstone Conglomerate and the Formation of Stratified Sand Rocks. Cleveland, 1854, pp. 16.

‡ J. S. Newberry: Ohio Geol. Survey, vol. ii, part 1, 1874, p. 111.

humic acids which were evolved in the process of its decay. This case, although suggestive, is not strictly comparable with those above described, since the solution may have taken place long after the burial of both pebbles and plants and under conditions somewhat different from those found at the earth's surface.

SURFACE INDURATION OF SAINT PETERS SANDSTONE IN WISCONSIN.

It is frequently observed that pure quartz sandstones have a decidedly different texture in their exterior and interior portions, the latter being soft and porous, while the former is hard and dense. A specific case is that described by Wadsworth,* who has shown that the Saint Peters sandstone in the vicinity of Mazominie, Wisconsin, where covered, is friable and composed of distinct grains, while in the exposed portions the sand grains are almost entirely obliterated, the rock possessing the conchoidal fracture and other characteristics of quartzite.

SURFACE GLAZING OF SANDSTONES IN PENNSYLVANIA AND TENNESSEE.

Again, the Medina sandstone in Pennsylvania and its southern equivalent, the Clinch in Tennessee, often shows a marked superficial induration, which in some cases converts the outer portions into a vitreous quartzite, and in others produces a thin surface glaze.

From the conditions under which this induration takes place it appears to be due to the solution of quartz in the interior portions of the rock and its transfer by capillary action to the outer portions, where the solvent is evaporated and the silica redeposited in the interstices of the sandstone.

Chemical Activity of the azo-humic Acids.

The wide separation of the localities at which these several cases of undoubted solution of silica occur precludes the idea that they are due to some peculiar and exceptional conditions, such as the presence of thermal alkaline waters. It seems more probable that they must be attributed to widespread agencies working in these cases under more than ordinarily favorable conditions, so that the effect is exceptionally striking. All the cases described occur in a heavily forested region, where there is an abundant layer of humus. In one case the pebbles receive the drip from a cliff above which is a long wooded slope; in another, the stream which at times covers the conglomerate heads in rather extensive swamps on the plateau and its waters are generally more or less deeply

* M. E. Wadsworth: Some instances of atmospheric action on sandstone. Proc. Bost. Soc. Nat. Hist., vol. xxii, 1883, p. 201.

colored with organic matter. There would thus appear to be present an abundance of the humic acids which are the intermediate products in the decay of vegetable matter between the original vegetable tissues and the final oxidation products, water and carbonic acid.

Thenard * has shown that while the simple humic acids are comparatively inert, they readily absorb nitrogen from the air, being converted into the azo-humic acids, the nitrogen not being present as ammonium, although it forms ammonium on the further oxidation of these compounds. The latter have a strong affinity for silica, combining with it to form a new series of acids in which the amount of silica is apparently proportional to the amount of nitrogen contained in the azo-acid. Thus Thenard found that simple humic acid dissolves only 0.8 per cent of silica, while azo-humic acid combines with from 7 to 24 per cent, depending on the content of nitrogen. The compounds thus formed are easily soluble in the alkaline carbonates, forming alkaline salts of the silico-azo-humic acids; but potassium carbonate must be abundant at all the localities where the etching has been observed, being supplied to the surface waters by the ashes resulting from the frequent burning of the forest litter.

Chemical Reactions involved in the Solution of Silica under atmospheric Conditions.

The principal steps in the complicated chemical process would appear to be the following: By the oxidation of the vegetable tissues in the process of decay the humic acids are formed, chiefly humic and crenic. These absorb varying quantities of free nitrogen from the air forming the azo-humic acids, which in turn combine with free silica. The resulting acids combine with alkaline carbonates, particularly potassium carbonate derived from ashes, to form easily soluble salts. It is quite probable that the presence of the potassium carbonate is an essential factor in the process.

In most cases the etched surfaces of the pebbles described above support a more or less abundant growth of cryptogamic vegetation, which in some cases forms a nearly continuous covering, and in others only scattering and very minute patches. It is most abundant on the pebbles in the bed of Clifty creek and least abundant on those at Nuttall, which receive the drip from a cliff and are thus kept wet most of the time. This vegetable covering might facilitate the solution of the pebbles in two ways—first, by supplying humic acids directly from their own decay, and, second, by absorbing solutions of those acids from other sources

* P. Thenard: Compt. Rend., vol. lxx, 1870, p. 1412.

and keeping the rock surfaces moist, so that their solvent action might be practically continuous for considerable periods.

Conclusions.

It seems probable, therefore, that the solution of the geodes and pebbles, concerning which there can be no question, was effected in the manner outlined above. While it is granted that such agents seem inadequate to produce the effects observed, no others suggest themselves. Moreover, as shown by Julien,* the activity of these agents is probably not generally recognized, nor their capacity both for producing specific and striking effects, such as those described above, and for effecting important geological changes upon a larger scale. If the above conclusion be correct, a solvent capable of removing a third or half of a quartz pebble an inch in diameter while still embedded in its matrix must be an extremely important factor in gradation when acting under the much more favorable conditions prevailing in the humus layer itself, where the surface exposed by the quartz grains is vastly greater in proportion to their bulk and where the solvent action is not interrupted as it must be on exposed rock surfaces.

*A. A. Julien: On the geological activity of the humus acids. Proc. Am. Assoc., vol. xxviii, 1879, pp. 311–440.

MARGIN OF BASELEVEL PLAIN ON HEAD OF MEADOW RIVER, GREENBRIER COUNTY, WEST VIRGINIA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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EROSION AT BASELEVEL *

BY MARIUS R. CAMPBELL

(Read before the Society December 29, 1896)

CONTENTS

Present Conception of the ultimate Result of undisturbed Erosion.

The cycle of erosion as outlined by Davis is now generally accepted as the normal succession of events in an undisturbed area, and its final result, the baseleveled plain, is likewise regarded as the great datum plain in all physiographic investigation.

Since this physical feature has attained such prominence in the study of modern geography, it seems opportune to inquire, What is the ultimate result of undisturbed erosion? Is it possible under such circumstances to produce a perfect plain, or will there always be irregularities of elevation and the surface remain merely a peneplain?

So far as the writer is aware, no one has attempted a complete analysis of the processes of erosion during the final stages of the cycle. It has been frequently said that the result is a baseleveled plain, but it is doubtful if the words have ever been used with their strict significance. Davis, who has so clearly described the processes of erosion in the preceding stages of the cycle, makes only a general statement like the following: †

> "Any mass of land constituting a single geographic individual or a natural group of such individuals must, as soon as it is exposed to the destructive forces of the atmosphere, begin its long sequence of development, and if no change of level happen to it, it must at length be worn down smooth and low to a featureless plain."

* Published with the permission of the Director of the U. S. Geological Survey.

† Methods and Models in Geographic Teaching; Am. Nat., vol. xxiii, p. 569.

The object of this paper is to present some facts which appear to have a bearing on this important question, and to suggest a theory regarding the processes of erosion at or near baselevel.

Local Baselevels in the Appalachians.

GENERAL CHARACTERISTICS IN THE AREAS OBSERVED.

During the progress of regular work in the Appalachian coal-field the writer has had the pleasure of observing several well marked baselevels which are doubtless of recent formation and which present some peculiar features that seem worthy of careful consideration. The most striking feature, and one which seemed to be generally characteristic, is the sharp line of demarkation between the level floor of the basin and the gentle slopes usually surrounding it.

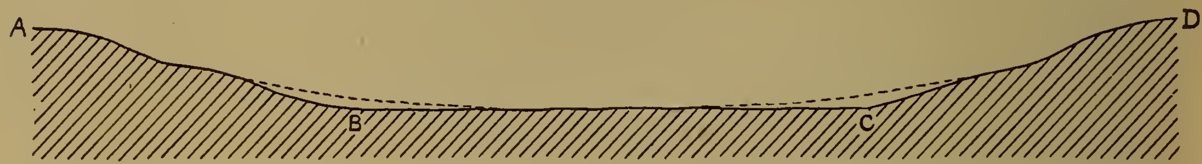


Figure 1.—*Ideal Cross-section of a local Basin in West Virginia.*

Figure 1 is a diagrammatic cross-section of one of these basins, in which the slopes *A B* and *C D* are seen to join abruptly the level floor *B C*. In some cases the abrupt termination of the erosion slope can be accounted for by the presence of a stream near that side of the basin, but in many cases there seems to be no relation whatever between the location of the stream and the sharp cutting at the foot of the slope, for the line of separation can be traced continuously around all of the sinuosities of the corrugated erosion slope.

Figure 2 is an ideal sketch of the conditions observed in a number of instances.

In many cases the disposition of the hard and soft beds is such that the sharp line of demarkation appears, at first sight, to be due to this condition rather than to the general process of erosion; but more extended observations suggest that it is a general condition and not dependent upon the local character or attitude of the strata. The rocks are generally horizontal in this region or with scarcely appreciable dips; consequently if a hard bed of sandstone interrupt the development of any of the drainage lines, the basin which forms above the barrier will necessarily be floored by the same bed, and there will be a decided difference in the rate with which erosion operates on the floor and on the sides of the basin. In several instances, however, the bed forming the barrier is slightly folded in such a manner that it does not appear above the point where it arrests the stream, and the basin is cut entirely in the softer stratum overlying the sandstone.

In the best developed baselevels in the region, the barrier is formed by the gently upturned edge of the Pottsville series, and the basin above is cut in the Mauch Chunk shales. Plate 20 is a photograph of the margin of this plain on the headwaters of Meadow river, Greenbrier county, West Virginia. Owing to the softness of the shales, the peneplain is wonderfully developed along the larger streams and even extends to the heads of all of the small ravines which drain into Meadow river.

FIGURE 2.—*Ideal Sketch of the Margin of a local Basin.*

PECULIAR CHARACTERS NOT EXPLAINED BY PRESENT THEORIES.

Every basin in this region receives the overflow waters from an area of greater or lesser extent immediately surrounding it. In many cases this drainage basin may be of considerable magnitude, but in all cases it consists at least of the immediate erosion slopes which descend toward the plain. No matter how short these slopes may be, they yield at every rainfall a certain amount of material derived from the decay and disintegration of the rocks forming the slopes, and this load of waste is transported from its place of origin to the floor of the basin.

In the light of previous knowledge respecting the operation of erosion at baselevel, we should expect to find this waste deposited in an irregular band around the margin of the plain, as indicated in cross-section by the dotted lines in figure 1. This deposit of waste would serve to unite and blend the erosion slopes with the floor, giving to the basin a U-shaped cross-section. As a matter of fact, however, the two surfaces are found to be sharply differentiated in most cases, and therefore it seems probable that the waste is removed by some process from the floor of the basin as fast as it is supplied.

Since these level floors are due to erosion and not to sedimentation, and since the streams have too low a grade to transport mechanically this material, its disappearance seems to imply that near baselevel there may be processes of erosion at work of which at present we have but an imperfect knowledge.

We can very easily account for that portion of the material in question which is usually considered soluble, but there is a much larger part which is regarded as insoluble under ordinary atmospheric conditions. How is this supposed insoluble residue removed? The sluggish stream which meanders through the tangle of swamp vegetation that flourishes on the moist floor of the basin is capable of transporting but a small percentage of the waste from the surrounding slopes. This waste is being carried down continually, and if the stream cannot remove it mechanically it must remain upon the bottom of the basin or be carried away by solution. Since the observed baselevels show little indication of deposition upon their surfaces, which is generally composed of rocks *in situ*, we are forced to the conclusion that much of this so-called insoluble waste is in reality soluble under certain conditions which appear to be present during the process of baseleveling.

Evidence of Solution at Baselevel afforded by etched Pebbles and Geodes.

The occurrence of etched pebbles of vein quartz and of etched silicious geodes, as described in the preceding paper, would seem to indicate that under certain conditions of weathering even the most resistant form of silica is readily dissolved, while the more soluble forms are acted upon almost as readily as limestone under ordinary atmospheric conditions.

The conditions under which the pebbles of vein quartz, found by Mr Hayes on Clifty creek, Tennessee, were etched is very similar, apparently, to those which prevail upon a baseleveled surface. Clifty creek is upon the Cumberland plateau, which is formed by the horizontal beds of Coal Measure sandstones and conglomerates. Upon this surface the streams are sluggish, often obstructed by a heavy growth of vegetation, and in many respects the conditions simulate those which must have prevailed when this same plain was near sealevel. During the summer season the water of these streams is loaded with the products of decaying vegetation to such an extent that it becomes brown in color and disagreeable to the taste. If the swampy condition of the plateau adds to the water of its slowly moving streams such a strong solvent, what must have been the character of the water of the streams which meandered over the same surface when it stood at sealevel and was covered with the rank growth of vegetation which must necessarily have prevailed during the Cretaceous cycle?

The etched pebbles found by the writer at the base of the Nuttall cliff on New river are apparently the result of conditions similar to those which prevail on the Cumberland plateau. The coarse conglomerate serves as a reservoir from which the plants derive sufficient moisture to enable them to flourish even in very dry weather. Although this growth crowns a cliff with a vertical face of over 100 feet and this cliff in turn forms the crest of a gorge 1,000 feet in depth, still the upper surface of the conglomerate presents essentially swamp conditions, and the waters which trickle over the rocky face of the cliff are doubtless heavily charged with the products of plant decay.

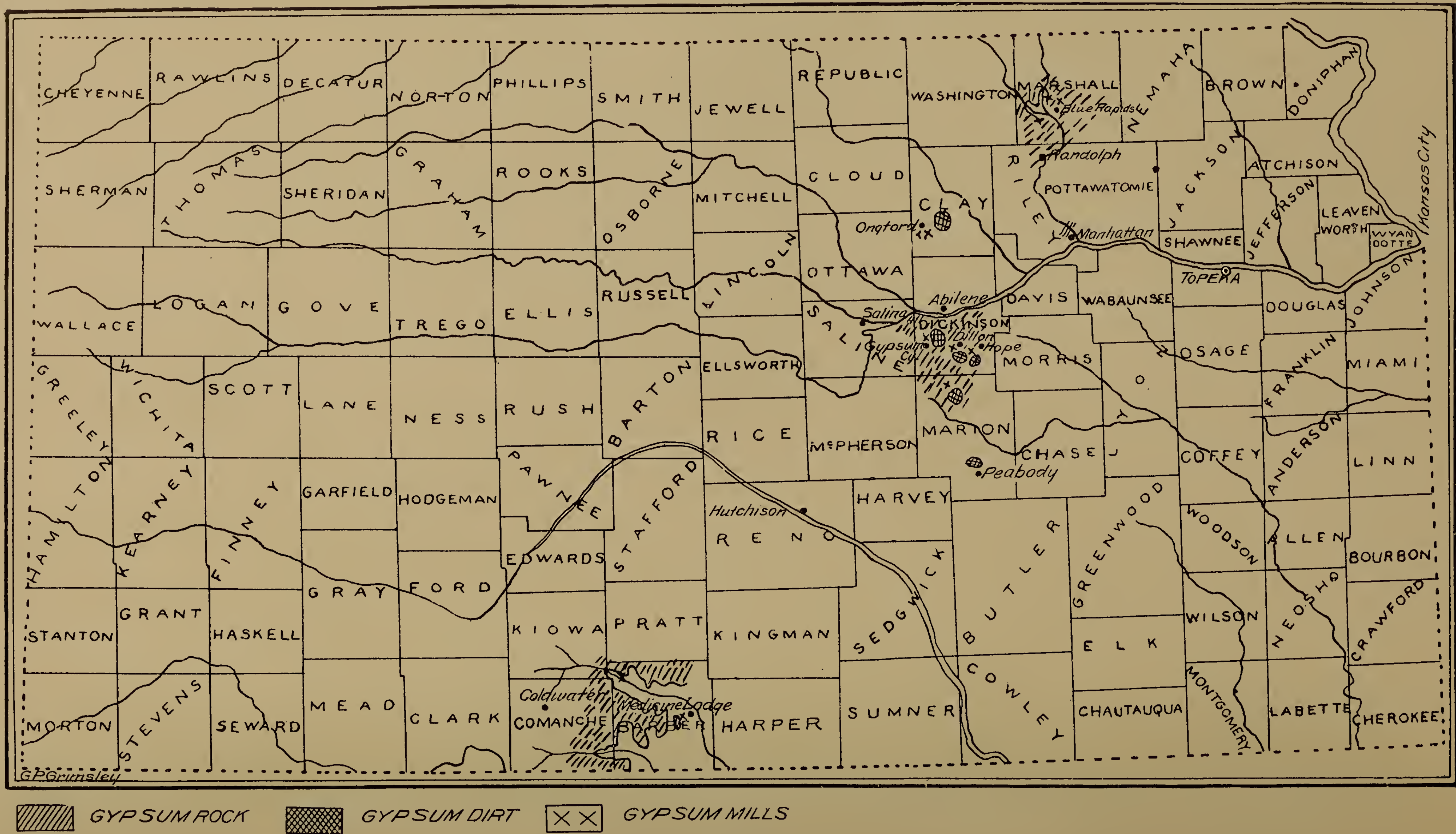
The geodes found by the writer in Overton county, Tennessee, though possibly composed of a more soluble form of silica, also show that a solvent is present at the surface of the earth in ordinary atmospheric conditions which operates readily upon this form of silica.

Conclusions respecting the Extent and Character of Erosion at Baselevel.

Altogether it seems to the writer that under certain conditions—conditions which are doubtless present on a peneplain approaching baselevel—the various forms of silica which make up the major portion of the rocks are soluble, and therefore are removed in a manner similar to the removal of lime and magnesia, except that the operation is much slower.

The sharp differentiation between the floor and the slopes of the observed basins indicates that practically all of the waste has been removed, but silica constitutes only a portion of this waste; therefore it seems highly probable that the remaining portion, consisting chiefly of the silicates of alumina, has also been acted upon chemically and carried off by the sluggish streams draining the basins. These residual compounds of alumina are usually in a more finely divided state than silica; consequently the streams may continue to transport them long after they have ceased to carry the larger grains of silica, and also after they have practically reached baselevel; but there will still be a portion, and perhaps a large one, which cannot be accounted for by this process, but which has disappeared, and such disappearance can only be explained by the theory of chemical action. If the effect of chemical action is noticeable in the small basins in West Virginia, how much more pronounced must its effects have been on the extensive peneplains of Cretaceous and Tertiary ages.

The facts herein presented, if correctly interpreted, indicate relatively intense chemical action on a surface at or near baselevel, and therefore have a direct bearing on the subject of land sculpture. The present theory regarding the operations of erosion during the closing stages of a cycle will need to be considerably changed, and likewise the generally accepted idea of the ultimate result will also suffer some modification. While our present knowledge of the processes involved is too slight to warrant more than mere suggestions, the subject is an attractive one and is certainly worthy of careful study, both regarding the chemical operations involved and the effect upon physiographic forms.



GYPSUM AREAS OF KANSAS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 8, PP. 227-240, PLS. 21-22 MARCH 8, 1897

GYPSUM DEPOSITS OF KANSAS*

BY G. P. GRIMSLEY

(*Presented before the Society December 31, 1896*)

CONTENTS

Introduction and historical Résumé.

In connection with the economic division of the University Geological Survey of Kansas I spent the greater portion of the summer of 1896 in the field investigation of the gypsum deposits in that state. In the fol-

* Published with the permission of the Director of the University Geological Survey of Kansas.

lowing pages I wish to present some of the more important results of that work which are of general interest.

Among the minerals of commercial importance in Kansas, gypsum occupies a prominent place, and has attracted the attention of prospectors and geologists for many years. Today, on account of the wide extent and purity of the deposits and the skill in manufacture, Kansas stands first among the states in the value of gypsum products.

In 1869 the Blue Rapids Town Company made a reservation of the Blue River gypsum deposits before selling their lands. Mudge briefly described in the First Annual Report of the Geological Survey of Kansas (1866) the gypsum deposits of the state, but he did not attempt to give their origin or age. This description appears in a number of his later reports with little or no change. In 1885 St John * describes immense beds of gypsum in the uppermost measures of the Carboniferous, which occur over a belt many miles wide across Kansas, with a thickness of 15 feet in the northern part of the state. In a later report † on the geology of southwestern Kansas the gypsiferous beds of that region are stated by St John to be doubtfully Triassic. Cragin,‡ in 1885, places the northern deposits in the Permo-Carboniferous and the southern beds in the Benton division of the Cretaceous. He ascribed their origin to the evaporation of a large saline lake which had no outlet. Later § he concluded that it was rather a gulf or sea formation than a lake deposit, and that it was Dakota in age.

In 1892 the late Robert Hay || devoted considerable space to gypsum in his paper on the "Geology and Mineral Resources of Kansas." He placed these northern deposits in the Permo-Carboniferous, and was the first geologist to describe the secondary gypsum dirt deposits of central Kansas. In a brief paragraph on this formation he gives the origin as due to the wash of adjacent deposits of gypsum, clay, limestone, and sandstone.

More recently Professor Cragin,¶ in an article on the Permian system of Kansas, states that the lower Permian of northern Kansas contains gypsum and rock-salt, and that the deposits of central Kansas belong to the lower Permian, or his Big Blue series. The southern Kansas deposits, described under the name of Medicine Lodge gypsum in his paper, are placed in the upper portion of the Permian, called the Cimarron series.

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* Fourth Biennial Report of Board of Agriculture.

† Fifth Biennial Report of Board of Agriculture.

‡ "Notes on the Geology of Southern Kansas," Bull. Washburn College Lab. Nat. History, vol. i, no. 3, p. 85, 1885.

§ "Further Notes on the Dakota Gypsum of Kansas," Bull. Washburn College Lab. Nat History, vol. i, no. 5, p. 166, 1886.

|| Eighth Biennial Report of Board of Agriculture.

¶ Colorado College Studies, vol. vi, 1896.

No reference is made to the origin of any of the deposits. The geological literature of Kansas contains numerous other short references to the gypsum deposits, but only the more important descriptions have been noted in this paper.

Location and Divisions of the Deposits.

The Kansas gypsum deposits of economic value form a belt trending northeast and southwest across the state. The belt of exposed rock varies in width from 5 miles at the north to 14 miles in the central part and to 36 miles near the southern line, with a length of 230 miles. This area is naturally divided into three districts, which, from the important centers of manufacture, are named: The northern or Blue Rapids area in Marshall county; the central or Gypsum City area in Dickinson and Saline counties, and the southern or Medicine Lodge area in Barber and Comanche counties. These areas appear to be separate, but careful mapping shows a number of isolated intermediate deposits, which serve to connect the northern and central areas. These connecting links are found near Randolph and in the reservoir excavation at Manhattan in Riley county; at Longford, in the southern part of Clay county, and near Manchester, in the northern part of Dickinson county.

Gypsum deposits of economic importance are reported from near Peabody, in Marion county, while they appear to be absent through Reno, Sedgwick, and Kingman counties, where the extensive salt deposits occur. There is thus a break between the central and southern areas, which is occupied by salt deposits.

From an examination of a map of west central United States, with the gypsum deposits indicated thereon, it will be seen that if the northeast line of the Kansas deposits is extended it will strike the Fort Dodge area in Iowa, and if it is continued to the southwest it will strike the extensive deposits of the Canadian river in Indian territory and those of Texas.

Topography.

Northern Area.

The phrase "low monotonous prairies of Kansas" has no application to the gypsum belt, for there this feature is entirely absent. The northern area shows the remnant of a plateau of 1,250 feet elevation, which is now so indented by the Big Blue and Little Blue rivers and their smaller tributaries as to present a rugged topography. Toward the northwest and southwest the surface rises in hills 1,350 feet above sealevel. The valleys and hills are covered with fertile lime soils, and are dotted with prosperous farms, while numerous small towns are located in the valley of Blue river.

CENTRAL AREA.

The central area is located 70 miles southwest of Blue Rapids, and the gypsum deposits lie south of the Smoky Hill river, north of the Rock Island railroad and west of the Atchison, Topeka and Sante Fé railroad. The area is drained by the Smoky Hill river with its north-flowing tributaries, and the main watershed is 22 miles south of that stream. The district is a dissected plateau forming a very irregular surface near the divide, while the gradual northward sloping gives a smoother topography near the river. The main industry, the manufacture of rock plaster, centers in the towns of Dillon, Hope, and formerly Gypsum City.

SOUTHERN AREA.

The southern area lies 120 miles southwest of Gypsum City. The northern part is drained by the Medicine Lodge river and the southern part by the Nescatunga. The soft red shales and gypsum layers, which form such a characteristic feature of the region, are favorable to rapid erosion, so that the numerous tributary streams have excavated deep canyons, separated by narrow divides or buttes of red clays and shales, with interlacing selenite layers. These are often 150 feet above the bottom of the canyons, and they are capped by the massive white gypsum, producing an effect very much like that of the "bad lands" of the northwest. These features are well shown in plate 22, figure 1.* This whole region presents the most rugged topography to be found in the state, and forms scenery of great beauty, especially interesting to the geologists through the lessons in erosion it so clearly depicts.

Blue Rapids Deposits.

Three companies are now engaged in plaster manufacture in the northern area. The gypsum occurs as a mottled gray rock of saccharoidal texture, breaking with irregular fracture. It is more or less crystalline, showing fibers and plates. The top is covered with a layer of white satinspar needles, which stand normal to the gypsum ledge and vary in length from one-fourth to one and three-fourths inches. The rock is irregularly traversed by blue clay seams, which contain a small amount of carbonate of lime. On exposure to the air for some time or when

* Made from a photograph taken and kindly loaned by Professor Prosser, of the Kansas Geological Survey.

FIGURE 1.—NORTHERN END OF GYPSUM HILLS, KANSAS

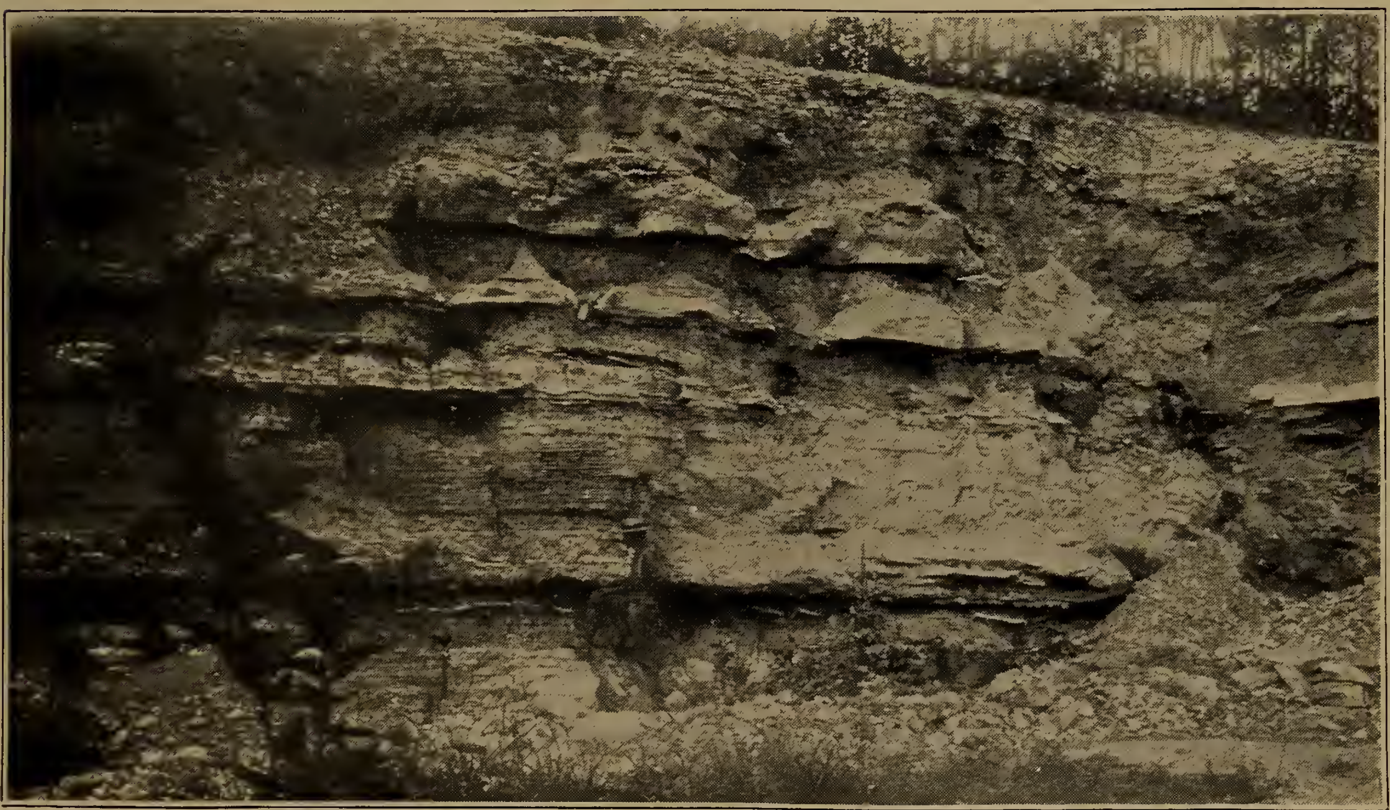

FIGURE 2.—MERRILL GYPSUM QUARRY, KANSAS

GYPSUM DEPOSITS OF KANSAS

crushed, the rock becomes snow white. Throughout the Fowler Brothers' mine, northwest of the town of Blue Rapids, there are numerous cutters or veins filled with transparent crystals of selenite, often of great perfection. The section at this mine, which is almost the same as at the other mines (see figure 1) shows a limestone bed-rock of blue color more than 4 feet thick. On this rests the gypsum, with an average thickness of 8½ feet, covered by 8 feet of red and blue shales, followed by a thin limestone layer and 22 feet of buff shales, with another thin stratum of shaly limestone about the center. One hundred feet above the gypsum occurs a 30-inch stratum of buff fossiliferous limestone carrying a considerable amount of flint. This upper limestone occurs throughout the area.

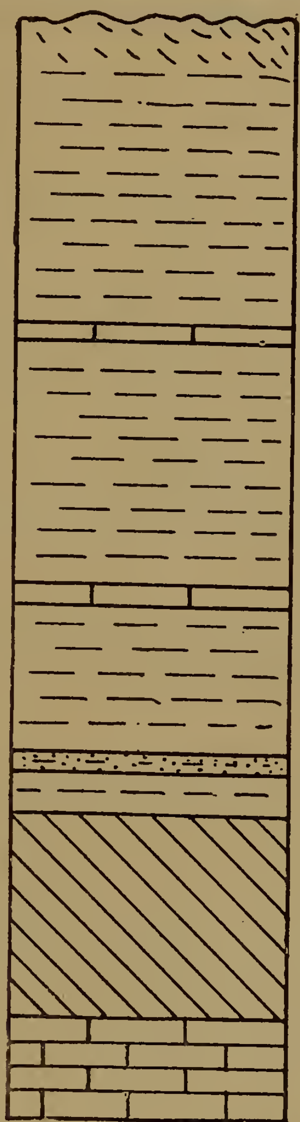

FIGURE 1.—*Section of Fowler Brothers' Mine.*

To the east of the Great Western mine, located north of the town, the Cottonwood Falls limestone is found about 20 feet below the gypsum horizon. The dip of the gypsum is slightly north of west, about 10 feet to the mile.

Gypsum City Deposits.

There are three well marked gypsum rock horizons in the central Kansas area. The lower and more extensive deposit extends over the central, northern, and western portions of the area; the second one over the central and southern parts, while the third is only found in a limited area in the southern part. The interval between the middle and lower deposits is 100 feet and between the middle and upper 40 feet. The dip of the three is south of west, with an average of about 6 feet to the mile.

In the northern part of the area, 6 miles southwest of Solomon City, on the bank of Gypsum creek, is located the mill and mine of the Crown Plaster Company. A section of the hill at the mine, represented in figure 2, shows 40 feet of shales and gypsum. The mine entrance is 20 feet above the water in the creek, and the stratum worked is 5 feet thick, underlaid by about 4 feet of shaley limestone. Below this there is a series of shales, with a 3-foot stratum of gypsum. The roof of the mine is a compact, dark shale, with a thickness of 3 feet. Above this come 2½ feet of buff shales and 2 feet of gypsum. There is an alternation of shales and gypsum to the top of the hill. The shales with the intercalated gypsum layers are folded and broken. The folds extend down into the mine, causing the shales of the roof to cut out the gypsum in many places, so that the mine probably will be abandoned before very long. This section is shown in plate 22, figure 2,* in which the man is standing on the top of the gypsum. The dip of the gypsum is north, toward the creek.

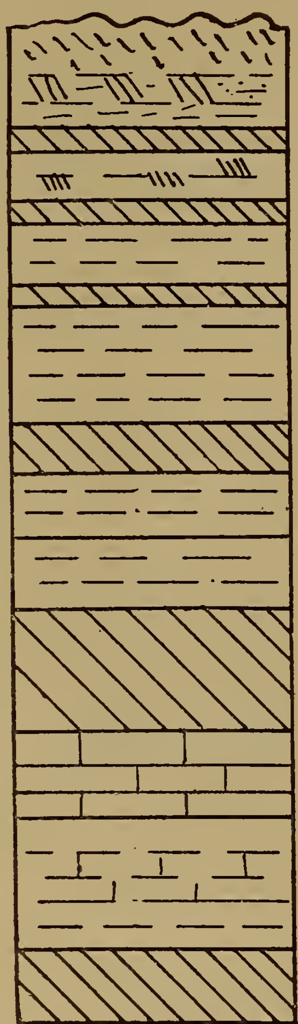

FIGURE 2.—*Section of the Crown Plaster Company's Mine.*

The lower part of the heavier gypsum layer is very compact and filled with oval crystals of yellowish brown selenite, having the greater length in the direction of the vertical crystal axis. The crystals are laminated by the pronounced pinacoidal cleavage. The larger ones are about seveneighths of an inch long and half an inch wide, and specimens from this portion of the stratum breaks with conchoidal fracture. The upper part is white, less compact, contains no oval crystals, and pieces break more irregularly.

At Hope, 20 miles southeast of Solomon, is located the mill of the Kansas Cement Plaster Company, which has been in operation since 1887. They first used the middle stratum quarried near the top of the hill, but in 1894 they sank a shaft 80 feet in depth to the lower stratum, which is nearly 14 feet thick. The rock is white, though much of it is traversed

* The two photographs were used by Professor Prosser in his paper in volume 2 of the University Geological Survey of Kansas and were kindly loaned by him.

by wavy dark lines which lie close together, giving an appearance somewhat like granite or gneiss, so that the plaster made from it is called by the company "granite cement plaster." The lower part of the stratum is compact, and contains rounded crystals of selenite with dark mottled surfaces. It thus bears a close resemblance to the Solomon gypsum already described, although the crystals are usually large, averaging about two inches by one. These are the only two localities in this central area where the gypsum rock is used for plaster.

Secondary Gypsum Deposits.

GENERAL CHARACTER OF THE MATERIAL.

At a number of places in the central area occur interesting secondary deposits of gypsum which form the basis of the greater portion of the plaster manufacture. This material is locally called "stucco," "gypsum dirt," and the like. It is a granular dirt found in low swampy ground, and is dark colored in place, but on drying assumes a light ash gray color. It is soft and incoherent, so that it is readily shoveled into cars, and it is ready for calcining with less labor and expense than is required in working the solid rock.

At the present time four of these deposits are opened in the central area, plaster being now made at three of them, and a fifth is worked to the north in Clay county.

DISCOVERY AND EXTENT OF THE AREAS.

The first deposit was discovered by Mr John Tinkler in the spring of 1873, near Gypsum City, when running a fire guard around a field. In 1889 he with others formed the Saline County Plaster Company, which built a mill at the edge of town. This was afterward sold to the Acme Cement Plaster Company, but they no longer use either the mill or the deposit. In 1892, 7,000 tons of plaster were sent from this mill to Chicago for the World's Fair buildings. This deposit covers an area of 12 acres and lies close to the surface with little or no cover. The maximum depth is 17 feet, while the average is 8. It resembles very much a fine sand bed or loess formation, and there is a tendency to break in smooth planes or joints. Organic matter occurs through it, and underneath is a layer of clay, and below this a deposit known as "black gypsum," which is considered worthless. On the east side occur strong springs. The top of the deposit is 20 feet above the water in Gypsum creek, a quarter mile to the west, and it lies in the valley of a small tributary creek. In a well dug on the hill above the deposit rock gypsum of good quality was struck 30 feet down, or 20 feet below the top of the dirt. No trace of gypsum was found in the hills above the dirt deposit.

A number of years after the discovery on the Tinkler farm a similar deposit was found near Dillon station, 14 miles eastward. This was purchased by the Agatite Cement Company, and the material closely resembles that at Gypsum City. Its extent is at least 40 acres, and it lies in swampy ground near a small creek. The greatest depth is 18 feet, and there is a surface cover of dirt of slight depth. Water from springs is very troublesome in working this deposit. The rock gypsum outcrops a quarter mile away at the same level.

A similar deposit is located 3½ miles southwest of Dillon, in a low place near a small stream, and here again springs prove troublesome. There is a soil covering of about 10 feet, and the gypsum dirt is 5 feet thick. Gypsum rock is not reported below this, but a heavy deposit is found on the hill about 30 feet above the dirt. The material is hauled to the mill close by and is the property of the Dillon Cement Plaster Company. Mingled with the dirt were shells and some bones, which were thought by the superintendent to be buffalo bones. Unfortunately they were lost, thus rendering identification impossible.

In Marion county, about 7 miles south of Banner City, the Acme Cement Plaster Company own a mill and a dirt deposit similar to the others. It is from 6 to 10 feet in depth and is near a small creek. The dirt rests upon sand, in which recent shells were found. Eighteen feet below the top of the dirt is a well marked gypsum ledge.

The Agatite Company have another mill near a dirt deposit at Longford, Clay county, 35 miles northwest of the Dillon mill. The deposit, which is near a creek, covers an area of 60 acres and varies from 2 to 10 feet in thickness. Other dirt deposits are reported from the same region near Manchester.

COMPARISON WITH FOREIGN MATERIAL.

These dirt deposits undoubtedly belong to the earthy variety of gypsum called by the Germans "Gyps-erde" or "Himmel's mehl," "Himmel's mjol" by the Swedish, and "gipsowaya muka" by the Russians. These varieties are described as loose, slightly cohering dust-like particles of yellow or gray color. The deposits are found near Neustadt, in Saxony; near Frankenhausen, Bohemia, Norway, and near Paris. The material in those places is thought to be identical with the "chaux sulfatee niviform" of Haüy. Its origin in these regions is ascribed to the solution of gypsum in water, and it is found often in fissures and is more abundant in wet than in dry seasons. At Frankenhausen it was observed on top of a gypsum mountain as a superficial stratum of about 1½ feet in thickness, not consolidated and still containing water. Its main use in those regions has been as fertilizer and for whitewash.

MICROSCOPICAL CHARACTER.

A microscopical examination of the material of the central Kansas deposits shows a considerable uniformity in character, as represented in figure 3. The dirt is seen to consist of a mass of small angular gypsum crystals of varying size. Perfect crystals are found, but most of them have their terminations somewhat rounded by solution. They are not transported crystals, but have clearly crystallized in place. Mingled with the gypsum crystals are small quartz crystals, seen especially in the Longford deposit. There is also a considerable amount of lime carbonate poorly crystallized and traces of organic matter.

FIGURE 3.—*Gypsum Dirt from central Kansas* (magnified 60 times).

MEDICINE LODGE DEPOSITS.

CHARACTER OF THE GYPSUM.

The Medicine Lodge gypsum is white, and in the lower portion of the stratum it is very compact. This portion is used at the Medicine Lodge mill for manufacture of *terra alba*. The upper portion has more of the sugary texture and is used in the manufacture of wall plaster. The satinspar which is found through the red beds below the gypsum is in the form of wavy plates, with perpendicular needles and variable in character. Some is soft and readily crumbles, while other portions are compact and glassy in appearance.

EXTENT OF THE AREA.

This southern gypsum area is the largest in Kansas, and, with its continuation in Oklahoma and Texas, forms the largest gypsum area in the United States. The rock extends from near the town of Medicine Lodge westward through Barber and Comanche counties, southward into Oklahoma and Texas, and passes under the Tertiary gravels to the north. The trend of the deposit is the characteristic one of the state—northeast to southwest.

The gypsum is first seen 6 miles southwest of Medicine Lodge, in an isolated range of hills 3 miles long and separated by a narrow valley from a second hill one mile in length. The valleys of East and West Cedar creeks, 2 miles wide, separate these hills from the next series, in which the gypsum plateau is continuous to the west. Medicine Lodge river cuts out the gypsum in a valley 6 or 7 miles wide. The northern limit of the gypsum cannot be determined, for it is covered with Tertiary deposits. Salt Fork and Sandy creeks cut out broad valleys to the south, and the streams in the eastern portion of Comanche county have removed much of the stratum; but the gypsum is continuous over the greater portion of western Barber and Comanche counties. The rock usually lies near the 1,800-foot contour line.

In the eastern part of Comanche county, on Cave creek, a second gypsum layer, 15 feet thick, is found 15 feet above the Medicine Lodge layer. This layer was called the "Shimer gypsum" by Cragin,* and it appears to be a local deposit.

GEOLOGICAL RELATIONS.

Looking west from the town of Medicine Lodge one can see in the distance a range of eroded hills with sloping sides and level tops. These hills extend in a north-and-south direction and are called the Gypsum hills. The sides are composed of the red clays and shales of the red beds, whose age is uncertain and much disputed, but they probably mark the transition from Permian to Cretaceous. The cap rock is a ledge of solid gypsum, which has protected to a considerable extent the underlying soft strata.

The base of the hills is a massive red sandstone, a second red sandstone is found 125 feet higher, and 100 feet above this comes the ledge of gypsum forming the top of the hills. This gypsum layer varies from 3 to 20 feet in thickness, depending upon the amount of erosion. The eastern portion of the area shows characteristic shore markings. Forty feet below the gypsum is a green gypseous sandstone two and one-half feet thick, which stands out as a prominent ledge through the hills. The red clays and shales below the gypsum contain an interlacing network of selenite and satinspar layers of variable thickness. This material has been dissolved out of the solid stratum and carried downward and redeposited through the agency of circulating water.

SOLUTION EFFECTS.

In the western part of Barber and the eastern part of Comanche counties the solvent effects of water on the gypsum are well shown, for here

* Loc. cit.

occur caves, natural bridges, and underground water-courses. On Cave creek, 4 miles west of Evansville, is the Big Gypsum cave in the Medicine Lodge gypsum, about 200 feet in length and 15 feet high at the east entrance. The western portion is low and covered with water, so as to be almost impassable. The section near the cave shows 30 feet of Medicine Lodge gypsum covered by 15 feet of red shales, then 15 feet of the Shimer gypsum. The natural bridges found in this region represent remnants of old caves or underground water channels whose roofs have for the most part fallen in, leaving the bridge as a clue to the former history.

Origin, Modification, and Age of the Deposits.

NORTHERN AREA.

The gypsum deposits of northern Kansas rest on a nearly level limestone floor over a large area. Although this limestone is an evidence of life, no traces of organic forms are found in the gypsum series above it, for life would be destroyed in a basin in which large quantities of gypsum were being deposited. Thus there is evidence of an abrupt change in physical conditions. Through some disturbance an arm of the sea was cut off, at least temporarily, and the evaporating water deposited gypsum. The dip of the floor is westward in the direction of the open sea of that time. The fact that the Blue Rapids gypsum contains clay seams irregularly distributed through it indicates that this gulf was a drainage basin for small streams. The foregoing conditions continued until at least 8 or 9 feet of gypsum were deposited, and then the old connection with the sea was either restored or the erosive and transporting powers of the streams were increased, so that the series of sandy shales buried the gypsum. It is not possible now to determine definitely whether evaporation continued long enough for the deposition of salt, but probably not, as there is no trace of salt detected in this region.

Much of the gypsum was subsequently removed by solution, for the upper surface is very irregular. This was accomplished before the consolidation of the shales, for they lie horizontal and are not folded to conform to the irregularities. This irregularity of the upper surface is shown in all the mines, but perhaps best in the Winter's mine, where the gypsum for 200 feet in the hill lies in long, rounded masses, with the long direction parallel to the hill slope.

The limestones with the Permian fossils and flint nodules, 50 and 100 feet above the gypsum and separated from it by buff sandy shales, indicate an increased subsidence of the area and a change in physical conditions favorable to life. Near the close of the Lower Permian or the

Neosho epoch the whole series of rocks—gypsum, shales, and limestones—was elevated and joined to the continent.

The water channels so well shown in the Winter's mine and the veins with the beautiful transparent crystals, in the Fowler mine indicate that water solution has produced marked effects in the later history of the deposits, effects which are even now in operation. The subterranean circulating waters have dissolved the gypsum, formed channels, and redeposited much of the material in fissures in the form of transparent crystals, or near the top as needles of satinspar. A glance at a map of the gypsum area shows one that a very large quantity of the rock has been removed by stream erosion, thus revealing to man the store of mineral wealth in these hills.

The geological sections show that the gypsum lies about 20 feet above the Cottonwood Falls limestone, which is taken by Prosser as the base of the Permian, and the gypsum belongs near the middle of the Neosho division outlined in his paper.

The cover of compact shales has served to protect the underlying gypsum from solution by circulating water to a considerable extent, thus explaining the absence of the marked solution effects noted in the area farther south.

CENTRAL AREA.

The evidence at hand indicates that the central Kansas basin is continuous with the northern and had the same origin—that is, a deposition in a shallow bay cut off from the western sea by a barrier. The dip of the rock is westward, and a change in conditions brought about a second deposit of gypsum, separated from the first by 100 feet of sandy sediment. At the Solomon mine the gypsum, intercalated with beds of shale, affords good evidence of the alternating conditions of gypsum-forming and sedimentation.

Abundant traces of salt occur in springs and in wells near the Solomon river, but no salt is associated directly with the gypsum. In the Hutchison-Kingman-Lyons region occur the large salt deposits which have placed Kansas in the front rank of salt-producing States of the Union. These beds belong to the Permian (at a lower level than the gypsum but farther out in the bay in the direction of the dip), and they represent a later stage in the gulf evaporation. The Saline-Dickinson gypsum deposits belong to the Marion division of the Permian, for the Dakota red sandstone is found on the hills south of Gypsum City, 300 feet above the lower gypsum.

The shales and gypsum in the Smoky Hill river region are irregularly folded and broken as a result of settling, possibly by the leaching out of former salt beds which rested over the gypsum and were much thinner than the beds farther south. The salt water percolated downward to rise again in the salt springs of that region.

The swamp deposits of earthy gypsum are clearly secondary and in age are geologically very recent. The deposits occur in low, swampy ground, and strong springs of gypsum water occur in nearly all of them. At the same level, or from 10 to 20 feet below the dirt, is a stratum of solid gypsum, while near most of these deposits no gypsum is found above. Near the bottom of the Rhodes deposit were found an Indian spearhead and recent shells of genera * *Planorbis* and *Physa*, while from the Dillon deposit the supposed buffalo bones were obtained.

Gypsum in an earthy form is deposited at the present time in dry weather to the extent of a half inch in a few days by the evaporatien of running water near these places. Where the gypsum water of the springs in these beds is evaporated there remains a crust of gray earthy gypsum resembling very closely the dirt. Sand, clay, and lime also occur in the deposit mingled with some organic material.

Part of the deposit in the form of silica, lime, clay, and gypsum has doubtless been washed from higher levels, but the greater portion has its source in the underlying gypsum rock. The circulating water has dissolved part of this ledge and carried it upward in the springs to the surface of the swamp, where the mineral was precipitated through evaporation, aided by the action of the organic matter of growing vegetation. The deposit accumulated through a comparatively short period of time and is even now slowly increasing in many places.

SOUTHERN AREA.

At a later period in the geological history of Kansas another extensive gypsum area was formed in the southern part of the State, Oklahoma, and Texas. This is found in the red beds which probably mark the close of Permian time. The ripple-marked sandstones associated with the Medicine Lodge gypsum indicate that the deposition was in a shallow bay, and its great thickness would necessitate a slow depression of the floor of that bay. The uniformity in character of the whole deposit shows that similar conditions were present over a large area. The absence of clay seams indicates that very little, if any, sediment was carried into the bay at that time, though the thick deposits of red shales below and above the gypsum show the sedimentation was great and only interrupted for a time, possibly the interruption being the result of climatic change. The dip is southward, and probably the gulf opened to the south or southwest, as the deposit thickens in that direction.

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* Discovered by Dr S. Z. Sharp.

Subsequent solution removed a great portion of the gypsum, which was precipitated in the shales below, where it is now seen in the interlacing network of selenite and satinspar. This characteristic feature is absent from the shales above. As in the northern gulf, a salt deposit occurs to the southwest in the Salt Plains district, but no trace of salt is found close to the gypsum.

Analyses of the Gypsum.

Through the kindness of Professor Bailey, of Lawrence, Kansas, the following analyses have been furnished. The percentages of carbonate of lime and silica are seen to be very high in the dirt deposits, while the percentage of sulphate of lime is lower than in the gypsum rock. There is also a notable increase in the amount of iron. The dirt is thus more impure than the solid rock—a natural result of its secondary origin:

	Hope Shaft Rock.	*Medicine Lodge Rock.*	*Dillon Dirt.*	*Longford Dirt.*
SiO_2	.34	.19	12.13	18.69
Fe_2O_3	.16	.10	.99	1.21
$CaSO_4$	76.98	77.46	64.63	56.56
$CaCO_3$	1.68	1.43	3.57	6.10
$MgCO_3$	1.38	.34	.88	.90
H_2O	19.63	20.48	16.80	15.54
	100.17	100.00	99.00	99.00

Conclusions.

The gypsum beds of economic importance in Kansas are all Permian in age, ranging from middle Permian or Neosho to the close. They cover a belt approximately 200 miles long, 10 miles in width at the north, 20 miles in central Kansas, and 60 miles in the southern part of the state. The deposit is 8 feet thick in northern Kansas, 14 feet in the central area, 25 feet in the southern area, and farther south even thicker. It will thus be seen that the deposit increases in width and thickness southward. The northern and central rock gypsum was deposited in the same gulf cut off from the western Permian sea, while the gypseous dirt deposits are secondary and of recent age. The southern deposit was formed in a shallow bay cut off from the Permian sea not far from the close of Permian time. Salt appears to have been deposited in these bays, but now it is only found farther out in the old gulf.

Washburn College, Topeka, Kansas,
December 28, 1896.

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EVIDENCES OF NORTHEASTERLY DIFFERENTIAL RISING OF THE LAND ALONG BELL RIVER

BY ROBERT BELL

(*Presented before the Society December 31, 1896*)

CONTENTS

INTRODUCTION.

It is generally admitted by geologists that a differential rising of the land toward the northeast has taken place in Pleistocene times over a great breadth of North America, extending from the Canadian northwest territories to the New England states. The unequal elevation of the land has been demonstrated by Tyrrell in Manitoba, Canada, and, among others, by Chamberlin, McGee, and Leverett in the western United States, by Lawson around lake Superior, by Spencer and Taylor in Ontario, Canada, and by Gilbert, Spencer, Upham, Fairchild, and others all the way from Ohio to New England.

There is the plainest evidence that at a very recent geological period the land has been rising all around Hudson bay and in the Arctic and sub-Arctic regions of the Dominion as well as on the Atlantic coast of British North America. It would be, *a priori*, unreasonable to suppose that such an extensive earth-movement could suddenly cease. That it has not ceased, but is steadily going on at the present day around our great inland sea, was, I think, demonstrated to the satisfaction of this Society at the annual meeting last December, in a paper by the writer on "Proofs of the rising of the land around Hudson bay."

The object of the present article is to state what the author considers to be evidence that the uplift now going on is not uniform, but that the old differential elevation toward the northeast still continues. The evidence relates more particularly to one portion of the great region around Hudson bay, but there are phenomena of various kinds in several parts of this extensive territory which may help to prove that the differential movement is in progress over a wide area. Some of these may be here briefly mentioned.

Testimony of the Lakes.

CHANGES IN THE OUTFLOW OF LAKE TEMAGAMI.

Lake Temagami, between lake Huron and the Ottawa river, sends a tributary to each. Their outflow from the opposite ends of the lake, which is 30 miles long, is over clean boulders and solid rock, and yet the northern outlet is diminishing while the southern is increasing in volume.

ARRESTED OUTFLOW OF SAINT LAWRENCE LAKES.

The arrest of the outflow of the upper three of the great lakes of the Saint Lawrence by way of lake Nipissing and the Mattawa river, and the subsequent discharge of these lakes to the south in comparatively recent times, is another case in point. Several examples of dry beds of rivers, which apparently once flowed northward, have been seen by the author, but further investigation would be required to show that the change had not been due to the melting of glacial ice.

Testimony of the Streams.

RIVERS ON WEST SIDE OF HUDSON BAY.

On the west side of Hudson bay the Churchill river runs eastward parallel to the Saskatchewan-Nelson, at an average distance of 100 miles to the north of it. In the lower 500 miles of its course the Churchill flows at an elevation of 200 feet or more above the level of the other stream. At Frog portage, 500 miles from the mouth, the river is held up on the south side by a ridge of gneiss. At the lowest part of this ridge a portion of the water "spills" over and forms a chute with a fall of about 15 feet. The escaping water flows for more than 100 miles southeastward across the lower country toward the Saskatchewan river, which it joins at a point between 200 and 300 feet below the level of Frog portage.

RIVERS ON EAST SIDE OF HUDSON BAY.

On the opposite or east side of Hudson bay the two most southerly rivers of the Labrador peninsula, the Rupert and the "Broad-backed river," fall into Rupert bay. For the last 80 miles of their courses these streams run parallel to each other and are only about 7 miles apart all along. Although no distinct ridge intervenes, yet at the above distance from the bay the Rupert, which is the more northern, flows at a level of 50 feet above the other, and its elevation is there about 350 feet over the sea.

RIVERS OF THE LABRADOR PENINSULA.

The Labrador peninsula is 1,000 miles wide from east to west and the same from north to south. From the height-of-land down its center a number of large rivers flow parallel to one another directly west to Hudson bay. Each of these rivers appears to receive its principal branches from the north. Some of them, such as the Porcupine, the Little and the Great Whale rivers, throw off "lost channels," which run southward in every case, and in two they fall into the river next to the south, as in the case of the channel which escapes from the Churchill and runs to the Saskatchewan on the west side of Hudson bay.

RIVERS OF JAMES BAY.

The Albany and Attawapishkat rivers, which fall into the west side of James bay, in traversing the Laurentian country give off several "lost channels," always on the south side, some of which flow for many miles before they find their way back to the main stream. If these facts have any significance as to a widespread differential elevation, it is in favor of an increased uplift to the northward rather than in any other direction.

BELL RIVER.

Location and extent.—We come now to the consideration of the evidence bearing upon this question, which was observed by the writer during the past two years while surveying the new river north of the Ottawa, as well as its branches.

This river may be located upon the map by drawing a straight line from the city of Ottawa to the southeastern extremity of James bay. The central part of this line will lie near the course of Bell river, which is a large north-flowing stream. In crossing the watershed from the northern extremity of Grand lake on the upper Ottawa river the traveler makes four portages and paddles over three ponds, the total distance being four miles, to reach a navigable branch of this stream. On descending this he soon comes to a succession of lakes, the last of which is about 33 miles long. The stretches of river discharging these lakes into one another are broken by occasional rapids, and the total descent from the height-of-land to the last lake may be about 150 feet. Below this the northward inclination of the country becomes more gradual, and at a distance of 144 miles in a straight line from the height-of-land the river falls into the west end of Mattagami lake. This sheet of water lies east and west, or at right angles to the course of the river, and is the basin which also receives the drainage of a great tract of country extending all the way east to lake Mistassini, to the northward of Quebec. The united waters are discharged from the north side of Mattagami lake by the Nottaway, a larger river than the Ottawa, into the head of Rupert bay.

Discovery.—The existence of the Bell river was first made known in 1887, when the writer, who was then at Grand lake, sent his assistant, the late Mr A. S. Cochrane, to survey the upper part of a large river to the northward, which we had heard of from the Indians. Mr Cochrane surveyed and reported upon the first 70 miles of this stream below the height-of-land, and referred to it as "the unnamed river flowing into Hannah bay."* Up to that time the sketch maps of the region represented a stream called the Hannah Bay river or Harricanaw as traversing this region, and the Bell river was supposed to be identical with it; but the writer's instrumental survey of the whole river in 1895, and also of the Noddawai, demonstrated that it was a "new" river, or one heretofore unknown to geography, flowing at a considerable distance eastward of the Hannah Bay river. The stream had no particular name among the few aborigines of the region, and the present designation was suggested by the director of the Ontario Bureau of Mines, through the press, in October, 1895, and it appears to have been generally adopted.

Character of the channels and flow.—This large stream flows in the central depression of the district, and receives, in all, from either side, fifteen good sized tributaries. The largest of these is probably the Mekiskun, which flows rapidly down the east slope of the depression and falls into the lowermost large lake above mentioned. The lower 90 miles of the main river, following its general course, run in a broad valley overspread

* Summary Report of the Geological Survey of Canada for 1887, p. 24 A.

with a deposit of brown clay resting on till, and this section has a very gentle northward slope. The stream here consists of long dead-water stretches, broken by short chutes of a few feet fall where rocky ledges under the superficial deposits cross its course. The width in the still-water stretches is very irregular, but it averages about a quarter of a mile. In some places it contracts to two or three hundred yards and flows with an accelerated current between rocky shores. These contractions usually terminate in a sudden widening. On sounding the still-water stretches they were found to be unexpectedly deep, averaging from 30 to 40 feet at low water. The river all along looks as if something were choking the freedom of its flow, and even when the water is lowest, in summer, its channel appears to be brimming full. Except at the narrow parts, it seldom has any well defined banks. As a rule, the ground on either side slopes gently to the river and the trees grow quite to the water's edge. Although these slopes consist of soft earthy material, there is no uniformity in the rate of rise in going back from the river. The condition reminds one of what takes place when a stream is suddenly dammed up and the water floods into the uneven ground on either side. A cross-section of the channel is like that of a ditch rather than an ordinary river-bed. This condition is exceptional, and it has been rendered possible in the present case by reason of the low gradient of the river (about two feet per mile, including the chutes), the soft nature of its bed and banks, and its northward course. If we suppose the rate of slope to have been a little greater when the river first cut a channel large enough to accommodate itself through the soft deposits, and that afterward the flow of the water was impeded by a decrease in the grade, we should have the present state of affairs.

At two places where this part of the river bends to the northwestward it sends off channels on the southwest side into the level clayey country. The uppermost of these forms an island 16 miles long. Where the water leaves the main river at its head it takes a backward course, almost in the opposite direction from the current of the parent stream, and it must have been induced to fall off in that manner by some cause operating subsequent to the formation of the original channel.

At the foot of this long island the river turns directly west for a few miles, and in this interval two bays extend to the south. A new channel has been cut from the head of the uppermost across to the other, as if in response to a new pressure of the water.

Character of the tributaries.—If the flooded appearance, the irregular width, and the abnormal depth of the above-described portion of the main river be due to the cause supposed, we should expect to find the same appearances in its tributaries from the southwest or along the line of greatest change of level in opposition to the current; and we do find these conditions exhibited in a striking manner in such tributaries and in proportion to the opportunities afforded for the action of the supposed cause. Two cases in point will suffice for illustration. One of these is a branch which enters the main stream at the head of Taibis lake, from which a long still-water stretch extends to the northeast. The other is a river coming from the southwest and entering the western extremity of Mattagami lake. It may be named the Mattagami river. There is no parallelism in the two sides of these affluents. On the contrary, they are broken up into irregular peninsulas, bays, lagoons, inlets, or culs-de-sac, with islands here and there, these peculiarities being just such as we would expect to find if the water flooded back over a low but slightly undulating clayey surface. The accompanying outlines (plate 23, figures 1 and 2) from track-surveys of these two streams will illustrate the condition just described.

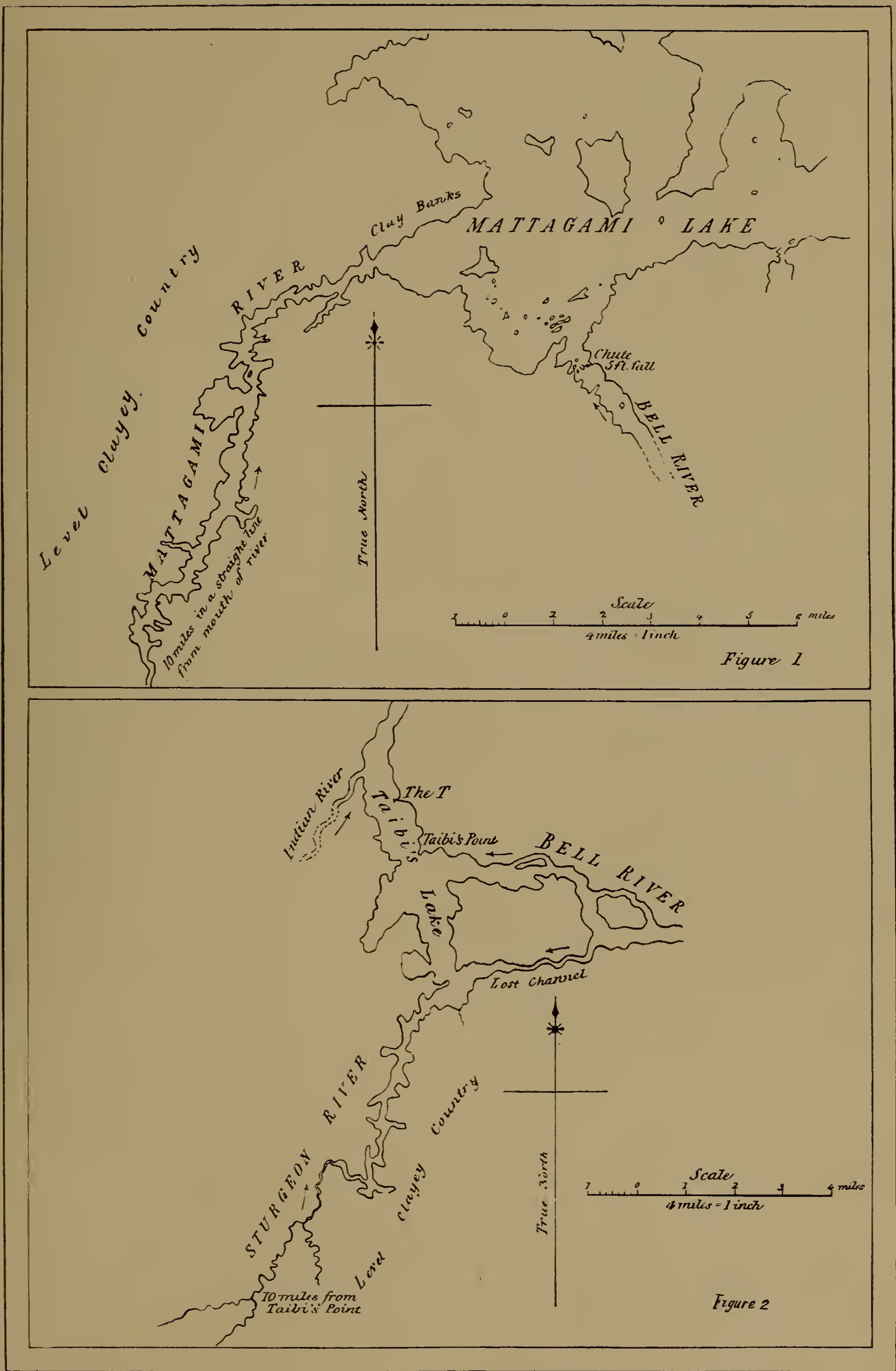
MATTAGAMI RIVER.

If the flooded condition seen in the Mattagami river be due to a very slight tilting of its bed in that direction, we should find a corresponding lowering of the water at the opposite end of the lake. Accordingly, on the north shore, about 5 miles from the east end, very conspicuous old water-marks are seen on perpendicular red granite rocks up to a height of 13 feet above the summer level, while the annual spring rise does not amount to more than about 5 feet.

At the foot of nearly all the low falls or chutes on this part of the river it was found by sounding that the water was considerably deeper than elsewhere, usually ranging from 50 to 80 feet. Mention has already been made of certain rocky narrows in this stretch which terminate in sudden widenings of the river. In these expansions, close to the entrance of the accompanying narrows and in line with the axis of the stream above, the water was always found to be very deep. There is little doubt that when the river flowed at a lower level these narrow parts were the sites of strong rapids and the deep-water expansion below each of them represents a flooded condition of the pool and widening which nearly always occur at the foot of such rapids in any river. If the water were now to be lowered by a slight increase in the grade of the present stream we would no doubt have chutes and rapids at these narrows, while the amount of fall in the low chutes which still remain would be increased.

NOTTAWAY RIVER.

A short distance below Mattagami lake the Nottaway expands into a sheet of water 30 miles in length, running north and south, called Soskamika (= "slippery shores") lake. The soft level clay land at its



MATTAGAMI LAKE AND ASSOCIATED RIVERS

southern extremity is being washed away by the waves. This land is covered by a forest of small spruce trees which are being undermined and falling into the lake. They have accumulated in immense numbers in one of the bays and present a curious spectacle. It would be difficult to understand why the flooding of the south and not of the north end of this lake should take place unless we suppose that its extremities are not maintaining the same absolute level.

What appears to be an interesting piece of evidence in connection with this question is afforded by certain long lived trees in a large swamp near the headwaters of the river. Some of our trees, such as the white cedar, the tamarack, and the black spruce, which grow in swamps, delight to have their roots bathed in the cool waters, but they like to have only so much of it and no more. Of all the trees of the forest none are more sensitive than these to an overdose of water, and none die more easily than they when a permanent rise in its level takes place. It may be said that the life of these trees is too short to be affected by the slight rise in the water from the almost imperceptible tilting of the surface; that the movement is too slow to have any effect on the life or welfare of a single generation of trees; but small and gnarled and half dead as these tamaracks and black spruces may appear, they nevertheless live to a great age. Their wood is hard and heavy, the rings of growth being closely crowded together. After attaining a certain size they retain their vitality for a very long time, but do not appear to get any larger. In these swamps the conditions for supporting vegetable life must be very uniform, and thus these trees can maintain their vitality for an indefinite period. The Indians say that in the course of their own lives they can see no change in them. In illustration of this subject it may be mentioned that an officer of the Hudson Bay Company told the writer that a few years ago, when he was traveling on the upper part of the Mekiskun river, on approaching the foot of a fall, where they were to make a portage, his old Indian guide called his attention to a dwarf black-spruce tree, or rather bush, projecting from an inaccessible rock in the fall, and told him that when he was a boy, more than fifty years ago, that bush was just the same size as it is now.

BRUSHY CREEK.

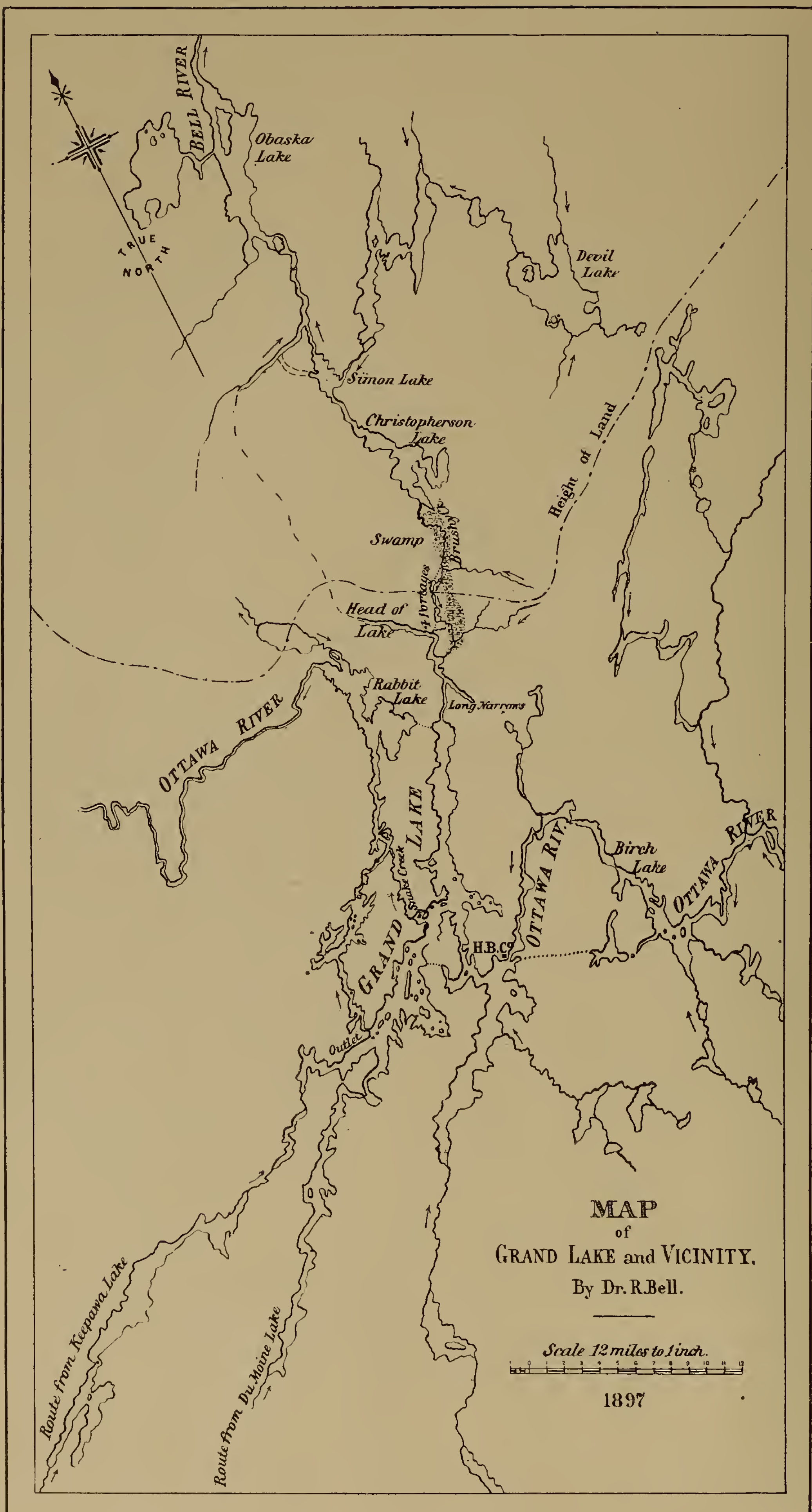
A large tamarack and black-spruce swamp occurs along Brushy creek, the highest branch of Bell river, and extends down to where it enters the south end of the uppermost lake on the river. A large proportion of the older and larger trees in this swamp are dead, and the others are slowly dying. The lake appears to be gradually flooding back upon the swamp and changing the conditions affecting these trees. Everywhere in the surrounding country the tamaracks and black spruces in the isolated swamps are perfectly healthy, and the above explanation seems to be the only way of accounting for the dying condition of those in the swamp at the head of the lake.

OTTAWA RIVER.

Change in its outflow and causes therefor.—The strongest evidence showing a differential elevation of the land toward the northeast is to be found in the total stoppage of the former northward outflow of Grand lake at its northern extremity, by which the waters of the Ottawa above it formerly passed down Bell river to Hudson bay. Although the outflow of this lake has been affected by a change of level of only a few feet, it has had the effect of shifting the position of the watershed of the large area comprising the hydrographic basin of the Ottawa river above the new outlet of Grand lake, which measures about 90 miles eastward and 60 miles southwestward. The evidence of the former discharge of Grand lake from the extremity of its northern arm is very striking, and one almost wonders why the lake does not still flow out that way; and probably it would resume its outflow by this old channel if its new outlet were dammed up so as to raise the present spring level only a few feet.

When the full volume of the Ottawa was flowing north there was probably a strong current through the Long narrows in that arm of Grand lake and also through Mink narrows, about one mile further north, in the same arm; but beyond these contractions the valley passing over the height-of-land widens out all the way to the northern extremity of Christopherson lake, a distance of 22 miles. In this wide part the current was checked and great quantities of sand were deposited in the still water. Bye and bye the sand choked the northward flow of the river and at the same time the rising water of Grand lake to the southward found a new outlet to the west at Snake creek over the low and almost horizontal ridge of gneiss which had heretofore kept the lake up on that side. Along the foot or western slope of this ridge and at a considerably lower level than that of Grand lake a rocky stream already flowed, which had heretofore formed the headwaters of the Ottawa. This channel, which was now greatly increased by the accession of all the waters flowing into Grand lake, zigzags among the gneiss ridges, but follows a general westward course all the way to lake Temiscaming.

By the washing away of the surface materials along its course the channel of the new outlet (Snake creek) would become rapidly deeper and the relief thus afforded at the northward outlet would cause it to cease to flow altogether, and this low barrier of silt now became the height-of-land between the waters of Hudson bay and the Saint Lawrence.



GRAND LAKE AND VICINITY

Closing of Snake Creek outlet.—Snake creek is only nine miles south of this low divide. After a time the rocky ridge at this place was lifted a little higher than the lowest point of the same ridge near the southwestern extremity of Grand lake and a second outlet now commenced to pour over it into the above-mentioned rocky stream along its western foot, and the Snake creek outlet has now also ceased to flow except at high water. Both these channels start nearly at right angles to the western shore of the lake, which has a length of 23 miles. The southern outlet is very fresh looking and starts as a rapid even in the lake itself outside of the general line of the shore.

Testimony of the Height-of-land.

The canal route across the height-of-land to Bell river leaves Grand lake by Sandy portage about 4 miles north of Mink narrows, already mentioned. In this distance wide flats of sand covered with coarse grass extend from either side, leaving only a narrow channel in the center of the arm. This is the only part of the lake in which such a condition exists, and it is a striking evidence of the permanent lowering of the water.

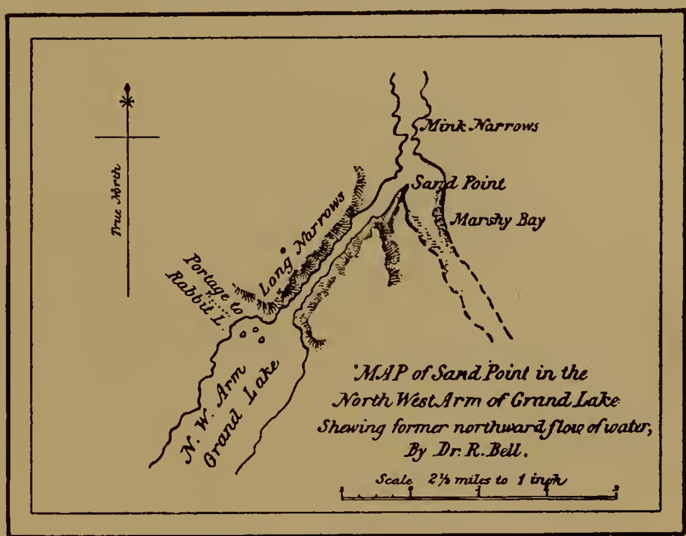


FIGURE 1.—*Sand Point.*

The banks of the Long narrows are high and rocky, and at their northern termination the eastern shoreline turns abruptly away. Here we find exactly what might be expected—a well-developed point of sand and gravel, raised several feet above the present level of the lake, leaves the high ground at the extremity of the narrows and juts out for 300 or 400 yards in the direction of the former strong northeastward current (figure 1). The present feeble flow of the water in the opposite direction has had little or no effect as yet in modifying the characteristic form of this point.

This locality and the topography of the country around the height-of-land are shown on the accompanying sketch map (plate 24). It will be seen that the probable course of the old north-flowing channel leaves Grand lake where the north arm bends west, and that it crosses a swamp to reach Brushy creek, the southernmost branch of Bell river. The three ponds on the canoe route lying west of the old channel have an elevation of about 50 feet above Grand lake, and there is a gentle descent from this lake to where the route falls into Brushy creek.

The writer had not time to personally examine the westward termination of the arm, which is about four miles beyond Sandy portage and which may be connected with some old river channel.

On leaving Simon lake the Bell river is rather narrow, but at two miles down it falls, like a branch, into a much wider channel, which continues upward to the southwest with curving parallel shores, and looks as if a large river had formerly flowed through it, but at present only a brook falls into it.

In connection with the subject of this paper, the fact may be worth mentioning that the present height-of-land at the northern extremity of Grand lake corresponds with the boundary line between the broad Laurentian region to the southward and the Great Belt of the Huronian rocks extending from lake Superior to lake Mistassini, a distance of 700 miles, and which is 150 miles wide on a north line from this locality.

LATEST DANISH MAP OF REGION NORTH OF UPERNIVIK

C, Cornell glacier; S, Mount Schurman

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FORMER EXTENSION OF CORNELL GLACIER NEAR THE SOUTHERN END OF MELVILLE BAY*

BY RALPH S. TARR

(*Read before the Society December 30, 1896*)

CONTENTS

Meaning of rugged Topography on the Greenland Coast.

VIEWS HELD.

From the earlier belief that the Greenland and American ice-sheets were united during the Glacial period there has of late been a reaction, and the pendulum has swung so far in the opposite direction that it is now said that the Greenland glacier has probably never extended so far beyond its present margin, but that many of the peaks of the islands and

*In making this study I am greatly indebted to all of my colleagues of the Cornell party, which besides myself was composed of the following: Professor A. C. Gill and Messrs J. A. Bonsteel, T. L. Watson, J. O. Martin, and E. M. Kindle. Each one rendered me much aid in obtaining facts, making suggestions, and in discussing conclusions. I wish also to express my indebtedness to Lieutenant Peary for the opportunity to make the study, as well as for the admirable way in which he carried out the plans which he laid before me. Above all, the party is indebted to Mr E. G. Wyckoff, of Ithaca, New York, who furnished the money for the expedition, without which the investigations would not have been possible.

peninsulas bounding the Greenland insular land mass escaped glaciation. This opinion has been expressed by both Professors Chamberlin and Salisbury as a result of their recent studies upon the Greenland coast.*

My conclusions, based on a study of a part of the Greenland coast in 1896, are of a directly opposite nature. All the land studied in any detail by the Cornell party was found to have been glaciated, and we saw no reason for believing that glaciers had not covered all the land and reached beyond it out to sea. Direct evidence of markedly greater ice extension was found on the Upper Nugsuak peninsula in latitude 74° 10′–15′. It is a statement of the conditions in this locality that this paper is chiefly intended to give.

CONSIDERATION OF THE EVIDENCE OPPOSING GENERAL GLACIATION.

As has been said, the Cornell party found no evidence opposing the theory of general glaciation; but both Chamberlin and Salisbury have put forward evidence of this nature. This is of two kinds: One the presence of a driftless area in the Inglefield Gulf region, announced by Professor Chamberlin, and a second the angular topography of part of the Greenland coast, described by both. The first I do not propose to discuss.†

The second evidence is that, although some of the land is noticeably rounded, other parts, and usually the higher areas, are angular. Distinctly angular peaks are said to rise above well polished and rounded valley bottoms and low hillsides. These facts are strikingly shown all along the Greenland coast, and in this respect I can agree to the observations; but my interpretation of them is quite different from that of Chamberlin and Salisbury. In this difference of topography I have found evidence that the ice had more work to do on the higher peaks, less ability to perform the work, and less time in which to do it than in the valley bottoms. Since it is diametrically opposed to the current belief, this interpretation needs amplification.

Other things being equal, a high peak is more rugged than the lower hills, because the action of the agents of denudation is more powerful. This applies to both preglacial and postglacial conditions; conse-

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*See particularly Chamberlin: Jour. Geol., vol. ii, 1894, p. 652, and Bull. Geol. Soc. Am., vol. vi, 1894, p. 219; and Salisbury: Jour. Geol., vol. iii, 1895, p. 875, and vol. iv, 1896, p. 769.

Since the above was written there has been a discussion upon this point, commenced by Professor Chamberlin, Jour. Geol., vol. v, 1897, p. 81, and continued in Science, 1897, pp. 344, 400, and later numbers.

† I would hardly be warranted in discussing the evidence from a region that I have never seen; yet I cannot let this opportunity pass without raising the query whether the topography in the neighborhood of the Greenland driftless area is not such that an area of this sort would naturally be expected. Was not the movement of the ice outward and the main stream down the Inglefield gulf? And is not the driftless area located in the place where the high Red Cliff peninsula might naturally have clogged the ice and hence prevented its action of erosion and notable transportation?

quently it may be expected that peaks rising two or three thousand feet above the valley bottoms were more rugged before the ice came and have been more denuded since the ice left than has been the neighboring lowland. That the latter is true is abundantly proved on every hand. High areas bearing glacially transported materials have been attacked by the frost and gullied extensively by the action of the snow water of spring,* while the rocks of the lowland are still distinct *roches moutonnées* forms, sometimes still grooved and polished.

The high peak rising above the valley, especially if this is broad, is not so readily worn by the glacier as the lower land. This is due partly to the fact that the ice-currents, deflected by the land topography, are more powerful and persistent in the valleys. That this is true is perfectly apparent, and we may see proof of it on the surface of the present glaciers of Greenland. In the valleys the ice projects beyond the average margin, entering the sea and there floating away in the form of icebergs. There is evidence of rapid movement in these valley portions and very slight motion over the ridges and peaks. The divide between two valley glaciers near the margin of the ice-cap is usually smooth and relatively unbroken, while the valley portion is intricately crevassed; but even over these divides there is some movement, as is shown by the stratification at the base of the land margin and by the debris in the ice.

Not only is there less rapidity of movement, but the peaks rising into the ice reach above the level of the debris zone, and thus have a relatively slight attack upon them. As this ice is mainly clear and moraine-free, the destruction must be mainly done by the ice itself, not by tools held in its grasp.

Granting for the moment that all the land was ice-covered, and that the present margin of the glacier is only one stage in the general retreat, there must have been a time when the peaks rose above the ice as nunataks, while the valleys were still occupied by glaciers. This condition must have lasted for a long time, and the same was true when the glacier began to encroach upon the land. First the valleys were occupied, then the hilltops were enwrapped, and finally all land was buried beneath the advancing ice-cap; hence the valleys were actually occupied very much longer than the mountains, and this necessitates not only a difference in ice erosion, but also a much greater preglacial and postglacial exposure to denudation for the mountain tops than for the valley bottoms.

For these reasons we may naturally expect the topography of the higher peaks to be very much more angular than that of the lower land, and there would be a marked difference in the ruggedness of peaks, according to even slight variations in rock structure and position as well

* See Tarr: American Geologist, vol. xix, 1897, p. 131.

as in land elevation. Moreover, there would be a variation according to the point of view. Seen from a vessel at sea, the peak will naturally be more angular than when viewed from the land side, which is the direction from which the ice moved, and hence in which the ice erosion was greatest. This difference in ruggedness would decrease as the time of ice action increased; therefore marked ruggedness may possibly be considered as an evidence that the ice covered the high land only for a brief period through this seems by no means certain, since there is little opportunity for ice erosion on the high points.

Instance of glaciated rugged Topography.

On the Upper Nugsuak peninsula (see plate 25), where the Cornell party spent a month, there was a chance to test the validity of this interpretation. The Devil's Thumb * rises about 2,650 feet above the sea-level and presents a seaward face of rugged outline (plate 26). Transported pebbles were found on its top. At the end of the Upper Nugsuak peninsula Wilcox Head rises 1,400 feet above the sea as a rugged and serrated peak, and upon it are patches of boulder-clay and innumerable transported blocks. Numerous other points on the peninsula reach to elevations between 1,000 and 2,600 feet. These higher peaks are very angular, but upon the tops of all of them that were ascended numerous transported fragments were found. On the crest of the nunatak named mount Schurman, about seven miles from the margin of the ice-sheet, transported pebbles were obtained at an elevation of 2,210 feet above the sea and 1,000 feet above the ice-surface at the western base of the mountain. This peak has been very recently uncovered, and is extremely rugged both in general form and in details. The rise of 1,000 feet on the western face is a precipice from top to bottom. If one fell from the edge he would pass entirely to the bottom. At the same time the lower areas of land in the vicinity of this peninsula are well rounded and smooth, as has been noted in other parts of the Greenland coast.

From this it may fairly be concluded that not only may we expect greater irregularity of form in the higher peaks than in the lower lands of a region that has been glaciated, but also that we have here in the Upper Nugsuak peninsula an excellent illustration of this. Views taken in various parts of this peninsula excel in ruggedness the peak which Professor Chamberlin pictures† as proof of nonglaciation, and yet upon its angular surface transported pebbles were found; also views of the same

* This is the Devil's Thumb as given on the Danish and British Admiralty charts. The real Devil's Thumb of the Arctic explorers is some 40 or 50 miles to the north of this.

† Bull. Geol. Soc. Am., vol. vi, 1894, p. 219; see also Salisbury: Jour. Geology, vol. iv, 1896, p. 773.

THE DEVIL'S THUMB

Elevation 2,650 feet; glaciated surface in foreground; rugged, angular topography in background on left. Transported pebbles obtained on crest of the Devil's Thumb. Photograph by J. O. Martin

FIGURE 1.—RUGGED TOPOGRAPHY, UPPER NUGSUAK PENINSULA

Uplands glaciated. Mountain peak 2,000 feet above base. View taken from elevation of over 1,200 feet. Shows also an excellent overturned fold. Photograph by J. O. Martin.

FIGURE 2.—ABANDONED MORAINE (mapped in figure 1, page 262)

RUGGED TOPOGRAPHY AND ABANDONED MORAINE

hill, taken from the sea and from the land, will furnish as good a contrast between rugged and glaciated topography as do the two contrasted views which Chamberlin published.* Not only do these glaciated hills present an angular topography when viewed from a distance, but there is also ruggedness of detail (see plate 27, figure 1). Some of this is due to postglacial weathering and erosion, which in these high latitudes is extremely active, but most of it is irregularity inherited from preglacial times, because the scouring action of the ice has not been sufficient to erase even these minor preglacial details. There are minute ridges and valleys of this nature,† and in the depressions, which are true strike valleys, there are deposits of drift, proving preglacial origin for these irregularities. Rock basin lakes abound in these depressions, and one may pass entirely around their margin upon a rock wall. These seem to be depressions caused rather by preglacial decay than by glacial erosion. They are often so small and bounded by walls so angular that origin by ice scouring seems absolutely impossible. Not only is there this evidence of preglacial decay and slight erosion, but in places the rock is so deeply disintegrated that it is certainly the disintegration of preglacial times. This decayed rock, recently uncovered, is sometimes found near the ice in a place entirely too deep to have been caused in postglacial times, and yet the rocks near by are rounded by ice-scouring.‡ The ice-action has been unable to remove this decay product, but in the lower areas, where ice-currents have been more active and longer at work, no such decayed material was found.

The evidence of this rugged topography and failure to remove decayed rock from certain places that have been distinctly glaciated is of course proof of slight ice erosion. This slight erosion may be due either to the short time of action or to the unfavorable positions presented by the higher land, or to both. That it may well have resulted mainly from the topographic peculiarities, and notwithstanding long continued action, I am perfectly ready to believe, though not able to prove.§ A peninsula rising to a height varying from 1,000 to 2,500 feet and varying in width from two to four miles descends into a fiord valley whose depth below sealevel is fully 600 feet in places. The valley is deep and broad, the peninsula high and narrow. Even with long continued ice action it can hardly be expected that the peaks of this region, rising well into the ice

* Bull. Geol. Soc. Am., 1894, vol. vi, fig. 15, opposite p. 219.

† Exactly this same feature was found in Baffinland, a region of similar though less differentiated topography, which has also been subjected to general glaciation.

‡ In one case the decayed rock still preserved glacial striæ, and the ice had left it so recently that lichens had not begun to cover it.

§ In this connection attention may be called to the fact that there are areas of preglacially decayed rock in New England.

and distinctly above the currents caused by the topographic irregularities, would be extensively worn.

Extension of the Ice over the Upper Nugsuak Peninsula.

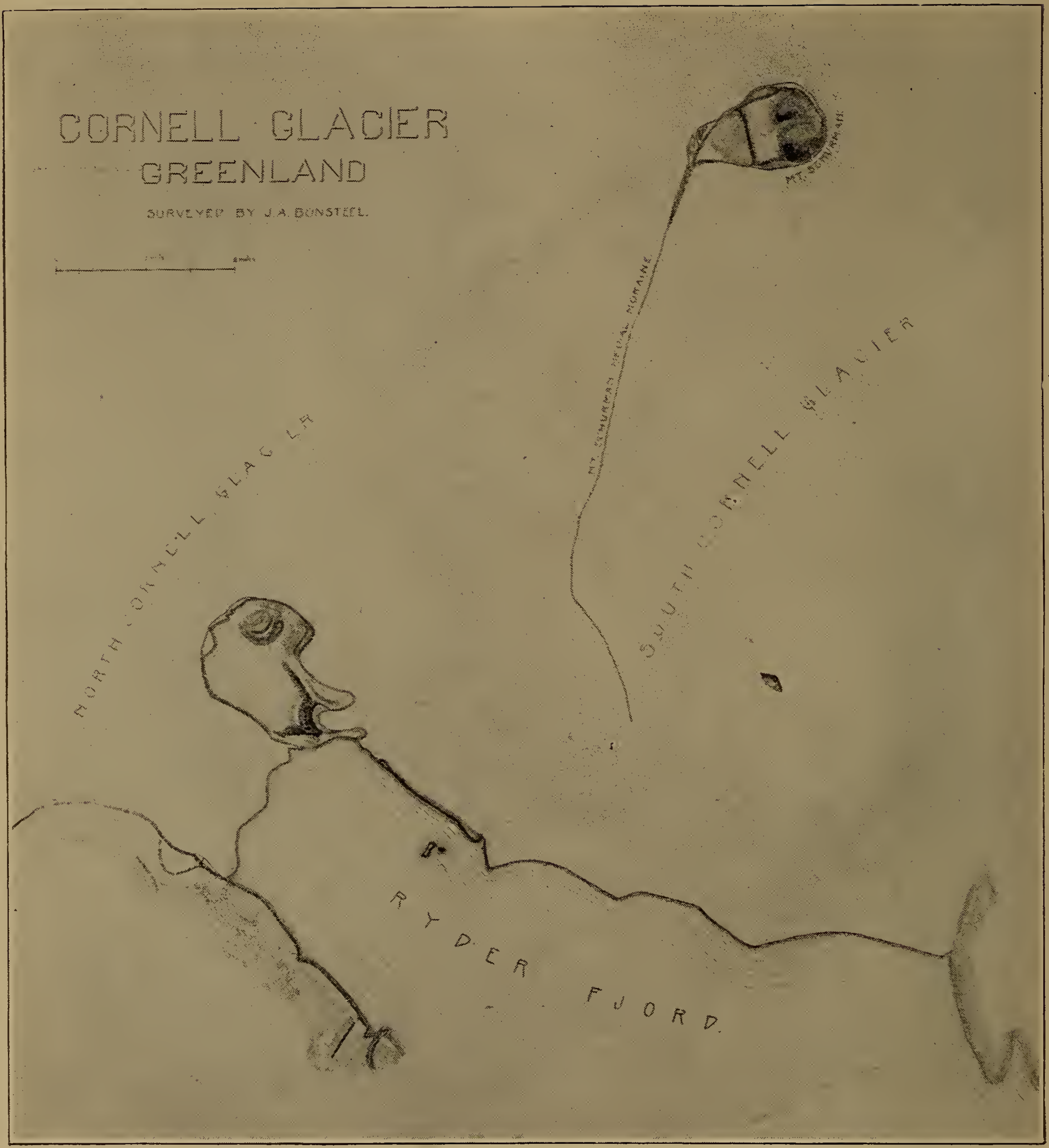
TOPOGRAPHY OF THE UPPER NUGSUAK.

This peninsula, which was made the base of our studies, is the longest arm of the land extending from this part of the Greenland coast. It stretches about southwest from the general coastline, and hence is not quite normal to its average course, which in this region is about north 15 to 20 degrees west (true north). From the ice-cap at the base to the extreme end of the Upper Nugsuak peninsula to Wilcox Head the distance is from 23 to 25 miles, and 8 or 10 miles farther, in the same line, are the Duck islands. Hence we have here a land area reaching to a distance of 30 or 35 miles from the present ice-margin The width of this land is nowhere more than 4 or 5 miles, and generally is only 2 or 3.

The elevation of the peninsula varies up to 2,900 feet, and there are many peaks reaching to heights between 1,000 and 2,500 feet. The topography is extremely rugged. It is evident that the narrow peninsula is a preglacial divide, and it is crossed by deep valleys, which often end in bays and fiords. These valleys extend across the peninsula, and in some cases have been perceptibly smoothed and grooved by glacial erosion. They have the appearance of mountainous valleys which have passed the stage of early youth, but were still young or adolescent when submergence transformed their mouths to fiords. This ruggedness of preglacial origin is increased by the effects of marked postglacial denudation. The hill tops and sides have been gullied by the mountain torrents, furnished with floods of water when the snow melts before the rising summer sun, and the valley sides and hill slopes have been encumbered with extensive talus accumulations of frost-riven boulders of great and small size. So rugged is the country from this cause that our average rate of progress over its surface on foot probably did not exceed one mile an hour.

The rocks are of metamorphic origin, and from a field study appear to have been derived from a sedimentary series. This has been intricately folded and faulted.* Among the rocks there is much variation in texture and in resistance to denudation, and hence the topography is often nearly related to the rock structure and position. This is especially well shown where trap dikes cross the metamorphic series, for their position is almost invariably marked by valleys. No sedimentary strata were

* The bed-rock geology was studied by Professor Gill, and he will publish his results after studying the thin-sections of rock.



CORNELL GLACIER, GREENLAND

found in place, and no other igneous rock than diabase. After the careful study made by Professor Gill and the diligent search of all the other members of the party, it is safe to say that no rocks other than trap, schist, and gneiss occur in place on the Upper Nugsuak peninsula.

On either side the peninsula is bounded by the waters of the fiords. Here and there islands rise above their surface, and in them there are occasional shoals. No soundings were made, but from the larger icebergs that float in the water and from the high ice-front of the glaciers that terminate in them, breaking off to form large bergs, it is evident that the water is deep in some places, and probably very often not less than 500 or 600 feet in depth. Between the Duck islands and Wilcox Head immense icebergs were constantly floating, though about half way between these two places bergs rising nearly 100 feet above the water were aground. A sounding made in this vicinity, at a distance of about two miles from Wilcox Head, in the direction of the Duck islands, showed the depth to be 114 fathoms. From an estimate of the height of the bergs which float though these waters, we had predicted the depth to be not less than 100 fathoms.

CORNELL GLACIER.

On the south side of the Upper Nugsuak peninsula there is a large glacier terminating in the fiord, to which the name Cornell glacier is given, and on the north side, ending in the Devil's Thumb bay, is another large glacier named the Wyckoff glacier.*

The latter was not studied in detail, nor was it mapped. Even late in August the sea ice had not yet disappeared from the foot of this glacier, and this fact, taken in connection with the scarcity of icebegs in the Devil's Thumb bay, showed that this glacier is not advancing rapidly. The southern boundary, separating it from the Cornell glacier, is a series of low but long nunataks, extending in the direction of the strike of the rocks. The outermost of these is fully 15 miles from the ice-margin.

The Cornell glacier (see plate 28) is a double one, divided near the coast by a partial nunatak named mount Hope. The southern arm is about $4\frac{4}{5}$ miles long, the northern about $1\frac{4}{5}$ miles. The sea-front is an ice-wall of remarkable whiteness and the surface is marvelously rough. Because of this roughness it seemed impracticable to obtain the rate of motion of the glacier, but from the small amount of ice coming from the front, the movement is evidently not very rapid. The land margin presents many features of interest, including distinct moraines. About 8 miles from the margin rises mount Schurman,† a nunatak reaching 1,000 feet above the ice on the western side. From this there extends a partial

* After Mr E. G. Wyckoff, whose liberality made the expedition possible.
† Named for President J. G. Schurman of Cornell University.

moraine stretching seaward, the sole blotch upon the otherwise universally white surface. Here and there the ice rises in the form of mounds several hundred yards in diameter and cracked upon the surface. These appear to mark the site of hills now buried beneath the ice, but near enough to the surface to produce an irregularity. To the westward of mount Schurman there is a mound of this sort, showing an elevated crevassed ice-surface when seen from the east, but proving the existence of the peak by the presence of land, which may be seen from the west or water side. This is a nunatak which is just now beginning to appear (see plate 28).

At present the Cornell glacier comes to the land at the base of the Upper Nugsuak peninsula, presenting either a steep slope or else a precipitous wall of ice, which is usually faced by a moraine embankment. West of it rises the land of the peninsula to the height of 1,000 or 2,000 feet above its present marginal surface. Turned to the northwestward and southwestward by this highland ridge, the ice creeps into the valleys forming the Wyckoff and Cornell glaciers; hence along this margin the ice movement is diagonal to that of the main ice-cap and the valley glacier tongues.

The moraine that is built along this land margin is made of very bouldery boulder-clay. The rock fragments are mainly gneiss, but in the moraine are found numerous pebbles and large boulders of a porphyritic red granite, of slate, and of quartzite. Somewhere to the eastward of the margin of the ice there must be a source for these materials, and it is mainly from a study of their distribution that the former glaciation of the peninsula was determined.

EVIDENCES OF FORMER ICE INVASION.

From the topography, excepting that of the lower zones, we obtained no help in our effort to determine the former extent of the ice-sheet. The ruggedness of the hills was such that from the topography alone no one would infer glaciation. Oftentimes, when viewed from the ice-cap or from the eastern base of the peninsula, the surface of the highlands can be seen to be distinctly smoothed; but the highest parts of the land invariably present a rather angular surface when viewed from the seaward or western side. As has been said above, this applies also to minor details; and decayed rock, evidently preglacial in origin, was found in several places.

In the highland portions of the peninsula the weathering has been so effective that the glacial striæ have been removed from the bed rock; but near sealevel, where the ice staid for the longest time, and from which it has only recently withdrawn, glacial striæ were found in numerous places. The same is true of till deposits. They were never found on high, steep hillsides, but were seen at several places in the lower parts of the peninsula, as well as in the lower valleys of moderate slope. A rather extensive boulder clay bed exists on the northwestern side of Wilcox Head, where it has evidently been brought from the highlands and accumulated on the northwestern or lee side of the hill. Near the top of Wilcox Head, also on the lee side of the ridge, upon a moderately steep upland, a bed of boulder-clay was found at an elevation of 1,200 feet above the sea.

Having determined the nature of the bed rock exposed, we were easily able to trace the former glaciation by means of the distinctly unusual transported pebbles and boulders of red porphyritic granite, slate, and quartzite.

The nunatak mount Schurman rises above the surface of the ice of Cornell glacier 460 feet on the eastern side, and on the western 1,000 feet above the surface of the ice. Upon the very top of this mountain transported pebbles were found, and one slate pebble with perfectly preserved glacial striæ on the under side was brought away.

Mount Hope, reaching 1,450 feet above the sea and 390 feet above the base of the ice on the eastern side, has also been glaciated over its entire area, but it has a broad, well rounded surface.

The Devil's Thumb (as marked on the Danish and British Admiralty maps, though incorrectly), rising 2,650 feet above the sea, at a distance of about five miles from the ice, has transported blocks upon its crest. A specimen of scratched slate was brought from here.* At numerous high points on the peninsula transported fragments were found, and all proof that we could obtain pointed toward the conclusion that every bit of land of this peninsula had been glaciated.

On Wilcox Head, in addition to the boulder-clay bed at an elevation of 1,200 feet, mentioned above, transported blocks of quartzite and red granite were found at an elevation of 1,400 feet above the sea 25 miles to the westward of the present ice margin. At the Duck islands, 8 or 10 miles from Wilcox Head, in addition to the bed of boulder-clay mentioned, numerous pebbles of quartz and red granite were found, and it was shown that the surface of this, the outermost land of this portion of the Greenland coast, had also been glaciated.

Amount of former Ice Invasion.

This is proof that the ice in this portion of the Greenland ice-sheet reached at least 30 or 35 miles to the westward. That is as far as there

* Obtained for me by Professor Gill and Mr Martin.

is opportunity to find proof. At the Devil's Thumb, 5 miles from the present margin, the glacier overrode an elevation of 2,650 feet above sea-level, and hence at this point had a thickness of certainly not less than 3,000 feet, for the depth of the fiord must be added to the mountain height, and then a certain amount must be added to the thickness in order that the ice might move and carry fragments to the top. I believe that at this place the depth of the glacier could not have been less than 4,000 feet, for there is such a steep grade from the present margin to the tip of the Devil's Thumb that to have moved up this and reached the tip, carrying fragments of slate derived from some point within the ice boundary, could hardly have been done by a glacier which merely veneered the mountain's surface. There must have been distinct movement, and that this was so is proved by the fact that, although extremely rocky and angular on the sea or western face, the back or eastern side of the Devil's Thumb shows distinct topographic signs of ice scouring. Even granting no more than 3,000 feet, which must be admitted, the ice-sheet here was a thick one.

Nearly the same amount of thickness must also be admitted for the end of the peninsula, where transported fragments were found at an elevation of 1,400 feet, while the fiord near it has a depth estimated to be 100 fathoms upon the basis of the size of the icebergs that float in its waters. A depth of 114 fathoms was found within 2 or 3 miles of this place, off the western side of Wilcox Head, in the direction of the Duck islands. Here, then, in the immediate neighborhood of Wilcox Head, the ice-sheet could not have been less than 2,000 feet in depth, and in all probability was deeper than this. At the Duck islands, adding their elevation of 100 feet to the water depth of at least 600 feet, it is necessary to believe that an ice-sheet existed at this point, from 30 to 35 miles distant from the present glacier margin, with a depth of not less than 700 feet and probably much more.

Therefore the evidence on this part of the Greenland coast is that the glacier of Greenland extended beyond the limit of the outermost land, carrying materials whose place of origin is within the present ice-boundary. In the places studied by various parties on the American side of these waters it is found that ice has also covered this land. Our party found that ice had covered the highest hills in Cumberland sound, on Baffinland, and had reached out toward the sea into the waters which separate Greenland and Baffinland.

From the evidence at hand, no one is warranted in assuming the junction of these two ice-sheets; but, on the other hand, it cannot now be denied as a possibility. On the two sides of a sea 300 or 400 miles wide the ice-sheet has recently extended beyond the outermost limit of the land. Where did it stop?

Recent Advance.

In the moraine near the sea end of the northern arm of Cornell glacier (north side) marine shells were found at an elevation of 50 feet above the sea and in such a position that they must have been brought there by the ice. The shells are of species now living in the fiord, and include *Saxicava*, *Mya*, etcetera. That they were not brought there by animals is proved by their abundance, and moreover by the fact that they were found embedded in the boulder clay of the moraine. This point also proves that they were not accumulated here by a change in land level. Whatever their sources, they were brought to these places by the same cause that built the moraine, and this is known to be the ice.

Mr E. M. Kindle later studied these is some detail and searched for them elsewhere. He was successful in finding them at an elevation of 586 feet above sealevel, at a distance of from 4 to 5 miles from the sea; and not only did he find them in the moraine, but also *in the ice itself.* Some were whole, but most of the specimens were fragments.

These observations confirm the conclusion that the ice is now advancing over an old seabottom at a distance of several miles from the present margin. Whether this means that the glacier is now removing fossiliferous preglacial beds, or whether some recent retreat has caused the fiord to reach some miles further inland than now, cannot be definitely stated. The latter seems the more probable, because it is difficult to believe that during all the time during which the ice has occupied this fiord, scouring the rocks of its margin to a depth below the zone of decay and rounding them to *roches mountonnées* forms, there should have been any of the soft-beds of the seabottom left. This of course is possible, but a slight retreat would equally and more naturally account for the phenomena.

There is apparently less energy of movement in the Cornell glacier than in glaciers in some other parts of the Greenland coast. It is possible that there is some topographic cause for this. If, for instance, the head of the fiord at the present margin of the glacier is not far from the divide, a very slight change in the supply may make a marked difference in the rate of advance of the glacier, so that even with slight variations in ice supply there may be marked changes in the glacier front. That there is some such topographic peculiarity as this is indicated by the surface of the glacier, which is elevated into numerous domes, evidently where hill-tops lie buried beneath it. At present these are overridden; soon this may be more difficult, and then, with the supply nearly cut off, the front will rapidly draw back. With a slight increase in supply again the hill may once more be buried by the ice and the front of the glacier can advance to its old position.

Present Boundary of Cornell Glacier.

It is not my purpose to speak here in detail concerning the many interesting features observed at the boundary of the Cornell glacier. This boundary was followed for many miles, and the ice-face and moraine-

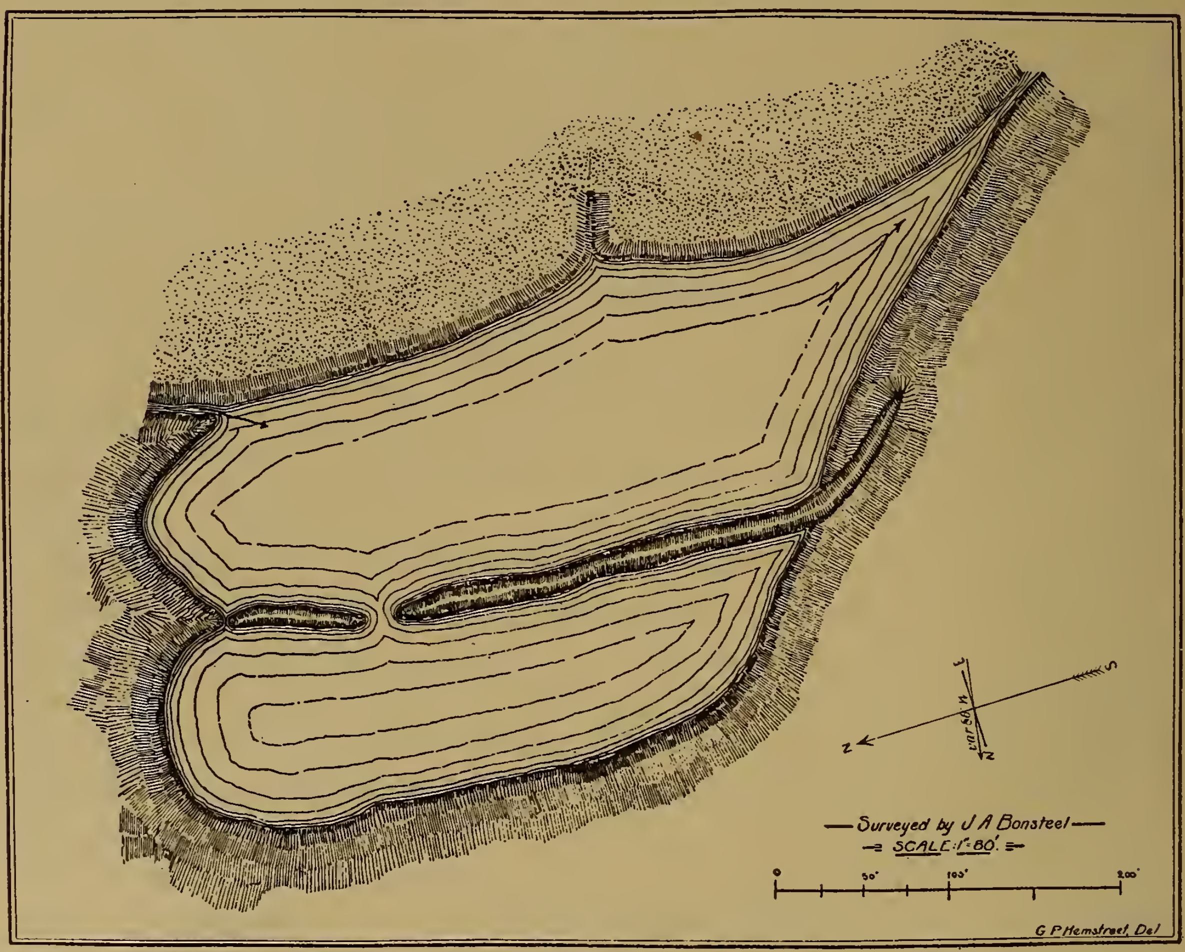


Figure 1.—*Marginal Lake near End of North Cornell Glacier.*

Showing position of abandoned moraine. Ice dotted.

foot studied. It was soon recognized that the front of this glacier was even now in process of change, and realizing the importance of leaving some record, by means of which at some future time the amount of change might possibly be determined, I selected the places that appeared to be the ones which promised to most delicately register changes of position. For this purpose the northern arm of the Cornell glacier was chosen. Numerous photographs were taken* to show the ice-front in various places, and several records were left from which the position of the present front was determined. These records are described in some detail below.

The first record is on the northern side of the north arm of Cornell glacier, about a quarter of a mile from the sea. Here a survey was made (August 18, 1896) of the ice-margin, an ice-dammed lake, and some moraine embankments of boulder-clay (plate 27, figure 2), left by the retreating glacier, the present margin of which was also determined (figure 1 of the text). The survey was made from a short baseline at an elevation of 60 to 100 feet above sealevel, in the amphitheater which forms the most marked indentation in this part of the present boundary. Here the steeply rising walls of the peninsula retreated from the ice for several hundred yards, forming a turf covered amphitheater whose length is about a quarter of a mile. Between the headlands of this indentation a shallow marginal lake is now held by a moraine dam. The baseline was marked by cairns at each end, and at the base of each of these a record was placed. The map made from this survey is reproduced as figure 1.

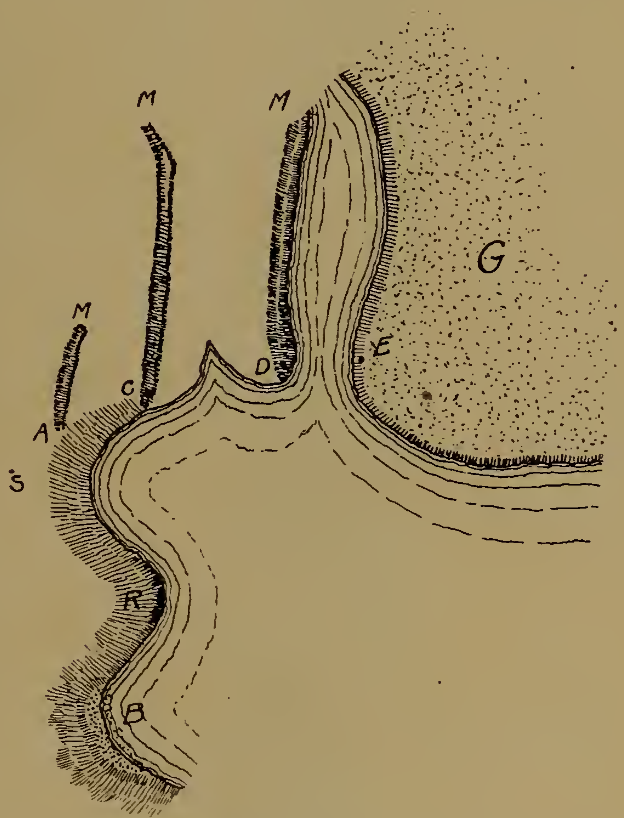


FIGURE 2.—*Northern End of Sea-front of Cornell Glacier.*

B, Boulder beach ; *R*, Rock point ; *G*, Glacier ; *S*, Transit station and cairn ; *M*, Moraine embankments. Distance from *A* to *C*, 133 feet ; from *C* to *D*, 212 feet ; from *D* to *E*, 110 feet.

Just below this place (toward the sea) the sea end of the glacier was marked (August 19, 1896) by a cairn left on the rock at a distance of about 40 feet from the sea and an elevation of 25 feet above it. From this the distance was measured by stadia readings to the nearest part of the ice-front, and also to the ends of the three moraines (more fully described below) marking stages in the present retreat of the ice. The location of this cairn and the position and distance of ice from it are approximately shown on the accompanying sketch (figure 2).

* Copies of these photographs will finally be added to the Geological Society of America series and the negatives placed among the collections at Cornell University.

The third cairn was built at the junction of the north Cornell glacier and the nunatak, mount Hope, just above the level of the sea (plate 29). Here a distinct T was cut in the rock (August 19, 1896) and covered by a large stone, which was protected by a cairn. This was placed three feet from the present ice-front, almost exactly where the glacier impinges upon the rock. Any advance of the ice will overturn the cairn and possibly obliterate the T. If the present retreat continues the cairn may be expected to remain.*

The final place to which attention may be especially called is the southern face of this nunatak. Mount Hope itself rises steeply above the sea, but it extends southward as a low ice-capped elevation. In the southernmost parts it is a mere cliff, reaching about 700 feet above the sea and capped by the ice, which reaches nearly to the margin. A tongue of south Cornell glacier extends northwardly behind this low hill, protrudes as a valley glacier tongue, and terminates in a lake. There is a photograph of the end of this glacier, and any future change in its outline can be easily determined by comparison with this. The main south Cornell glacier enters the sea on the south end of the low hill. In one place the cap of ice, which reaches to the tip of this hill and presents a low cliff toward the fiord, climbs over the cliff and passes down a low valley to the sea. Even a very slight change in the supply of ice must produce a very notable difference in the form of this delicately balanced tongue of the glacier. The photograph reproduced as plate 29 shows clearly the position and form of this. If this glacier is visited in the future, from these facts we may obtain a record of the movement in the interval.

Recent Retreat of Cornell Glacier.

There seems to be evidence that the Cornell glacier has been progressively withdrawing, and at present its front is certainly moving backward. One of the reasons for the greater ruggedness of the high peaks is no doubt longer exposure to postglacial weathering. The marked difference in freshness of the rounded rock surfaces in low and moderate elevations is proof of this. There is also evidence that the ice has occupied the lowland near the head of the fiord more recently than the parts farther out toward Baffin bay. Glacial striæ and fresh *roches moutonnées* surfaces abound near the present ice-margin, but they become much less marked and noticeable half way out toward the end of the peninsula.

* The place occupied by this cairn is just south of the high portion of the nunatak and on the south side of a narrow valley, now dammed by the ice and occupied by a lake.

FACE OF A PART OF NORTH CORNELL GLACIER

Showing mount Hope in the middle, with an ice-tongue hanging over the cliff and just reaching the sea. Mount Schurman is on the extreme right. View taken from height of 1,200 feet. Photograph by J. O. Martin.

In some of the inland valleys of the Upper Nugsuak, and particularly on the northern side of the peninsula, small glaciers even now exist, and one of them reaches to the sea.* From this latter glacier there is every gradation down to those that are hardly more than snowbanks, and in some places one is in doubt whether to call them mere banks of snow or glaciers. These are disappearing and represent the last stage in the withdrawal of the ice-sheet. That this is so is proved by two facts. Below some of the snowbanks striæ are found, showing that they once gathered and transported materials; also near the small valley glaciers, and especially near the one which reaches the sea, there are fresh striæ and bare rock surfaces not now covered by lichens and with the boulders fresh and unaltered. Not only is this true, but in several of the inner valleys there are striæ showing former but very recent glacial action where now no glaciers exist. The last phase of the ice occupancy of the Upper Nugsuak was that of the valley glaciers, at first extensive, now shrunken and almost destroyed. Probably this withdrawal is still in progress; certainly it has recently been.

Evidence of recent general retreat is also found on mount Schurman. Upon this peak, rising as it did above the zone of most rapid ice erosion into the clear middle layers of the glacial ice, there is little sign of glaciation. Its topography is rugged, and by postglacial weathering the striæ have been removed from the bed rock. However, even a small slate pebble has perfectly preserved scratches on the under side where it rested on the ground. It was not embedded at all, but merely laid on the surface, and so was partly protected from the air.

In addition to this evidence that the ice recently overrode the peak, the flora furnishes collateral proof. From the Duck islands up to the very ice margin, even to the nearly surrounded nunatak, mount Hope, the flora is well developed, and there is a great variety of lichens and mosses and great abundance of grasses and various flowering plants; but on mount Schurman, separated from this land by about 7 or 8 miles of ice, the flora is very different. Mosses, lichens, and some grasses are as abundant as at the end of the peninsula, but flowering plants are rare, excepting in the case of certain species which have light seeds. In other words, the light seeded plants, which can be distributed by the wind, have had time to reach the nunatak and take possession of it since the ice left; but the heavy seeded flowering plants have not found time to take a place on the mountain.

That these conditions of plant distribution are not due to any climatic features is apparent to any one who knows under what adverse condi-

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* See Tarr: Am. Geologist, vol. xix, April, 1897.

tions these Arctic plants thrive. Given a place to grow and a seed properly placed, the plant will develop and mature its seed in the short summer season. Moreover, even on the higher parts of this nunatak there are some individuals and colonies of the heavy seeded flowering plants; but these are scattered and are evidently spreading from centers. Wherever one is found there are generally others near by, but of some species only one colony was found on the entire mountain. The agents of distribution are the ptarmigan and snow-bunting, which could be seen flying about on the mountain side. The work of plant distribution has just reached this stage, and it is quite certain that there has not been a great lapse of time during which the land has been open to this distribution.*

Evidence of present Retreat of Cornell Glacier.

Evidence of recent retreat was found all along the ice-front. The valley glacier tongue of mount Hope (described above, page 264) has a fresh moraine fully 100 feet from its terminus. On the margin of this mountain a moraine is found at a considerable distance from the present edge of the main ice-sheet. In the same region a marginal lake has been able to change its place of outflow, thus lowering its level as a result of the retreat of the ice-edge. The old recently abandoned channel is distinctly seen; and that within a very short time it served to discharge the lake waters is proved by the fact that lichens have not yet begun to grow on the rock in the bed of the channel nor on the rock shores of the present lake below the old level.

On the moraine along the northern side of the north arm of the Cornell glacier we find the same evidence. The moraine embankment stands at a distance of 50 or 100 feet from the present edge of the ice, and it is not a part of the glacier, but distinctly separated from it as a true moraine, not debris-covered ice. This is frequently proved by the fact that the valley occupied by the stream which separates the moraine ridge from the ice, has cut down to the very base of the glacier. So recently have these moraine embankments been abandoned by the glacier that no vegetation exists upon them, neither lichens on the pebbles nor grasses in the clayey soil. In one place, at a distance of 35 feet beyond such a moraine and still farther from the ice, the bed-rock was found to be polished and scratched, and this so recently done that no lichens existed upon it. It is necessary to go 40 feet farther than this to find thoroughly lichen-covered rocks. Therefore at this place the lichens are following

*A botanical study of the nunatak flora would be of extreme interest.

the retreating glacier, and in some places have reached no nearer than 140 feet from its present edge.

Along the same margin, near the ice-front, there are three parallel moraine ridges (figure 2, page 263), the outermost being about 150 yards from the glacier margin, and situated upon the hillside. It is not bouldery, and hence is rapidly disappearing under the attacks of the weather. The second ridge is very long and sinuous, being quite like an esker in form. It extends a distance of half a mile parallel to the ice-margin and about 200 feet from it on the average. In its course it passes through the middle of the marginal lake (figure 1, page 262).

The moraine which lies nearest the glacier is just now being abandoned. In some places it is connected with the glacier, and everywhere is partly underlaid by ice. Since this is melting, the surface of the ridge is very muddy and irregular, because of the breaking down of the mound as the ice melts beneath. In some places it is entirely disconnected from the glacier. There is no vegetation on this moraine. On the middle ridge there is one species of grass, found in a few patches, and some lichens are growing on the pebbles. On the outermost moraine there are several species of plants. Beyond this there are other more indefinite ridges, evidently marking still earlier halts; but these are so ancient that they are entirely covered by vegetation.

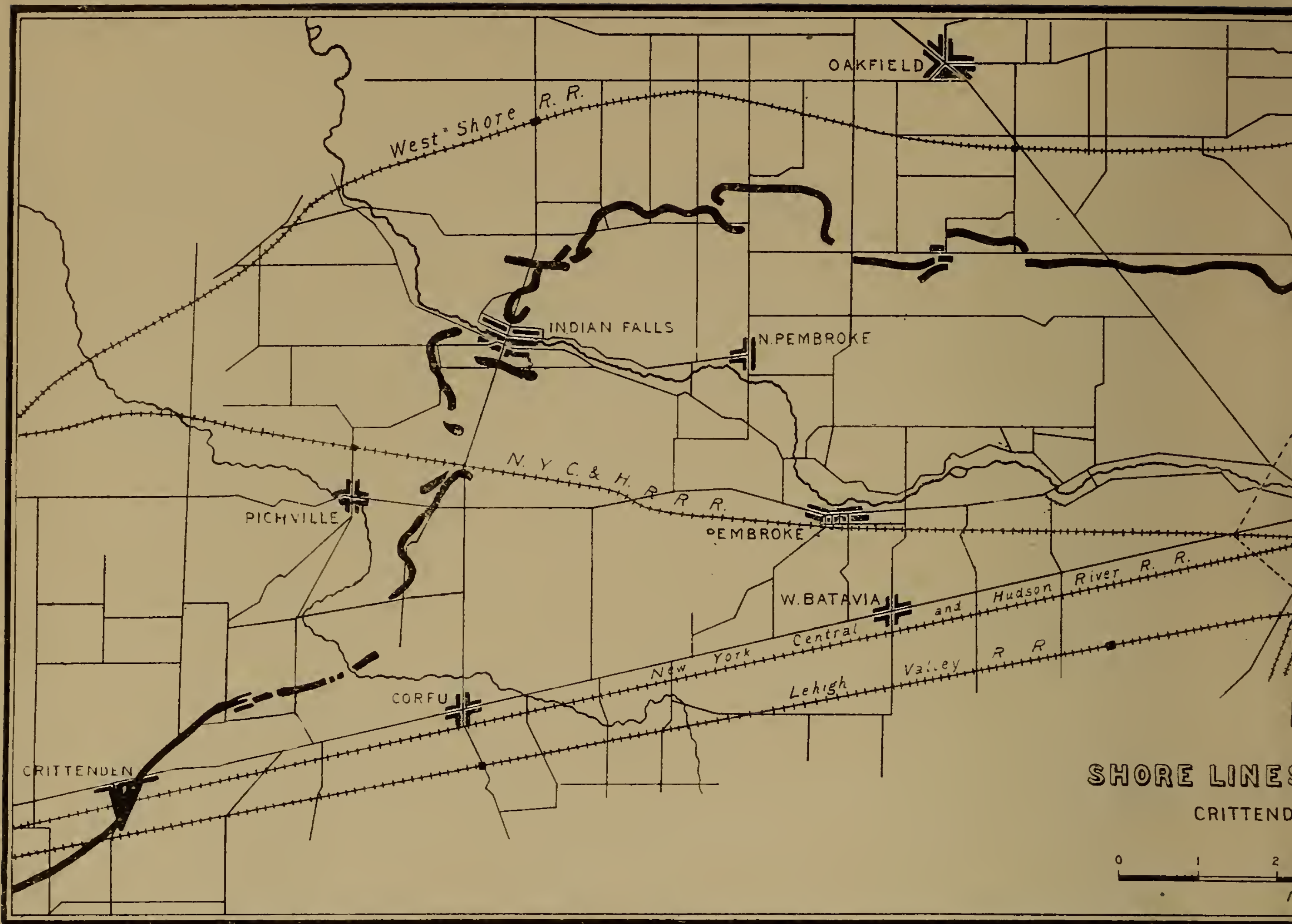
Summary of Conclusions.

The observations presented in this paper seem to warrant the following conclusions:

It is evident that rugged, angular topography does not necessarily indicate freedom from ice invasion. A rugged peak rising into the ice might for a long time retain its angularity. Such peaks are naturally more angular, both because of longer exposure to pre and post-glacial denudation, and also to the greater activity of denudation in the higher altitudes. Notwithstanding angular topography, the Upper Nugsuak peninsula has all been glaciated, and the ice-sheet has extended beyond the limits of the outermost land, the Duck islands, which lie 30 or 35 miles from the present ice-front.

There is no evidence which points to any particular limit of the ice advance, and, for all we can prove by distinct observations in this place, the glacier at one time may have joined the Baffinland ice-sheet. The glacier has recently withdrawn and is even now in process of retreat. However, the discovery of fossils and recent shells on the moraine and in the ice apparently proves that there has been a recent advance, preceding the present retreat. This former variation is not necessarily great in amount. There are no evidences to show the exact amount.

At present the ice is receding at a rate which promises to be measurable after a few years have elapsed. In order to make such measurement possible, records were left by the Cornell party at places which may easily be found.



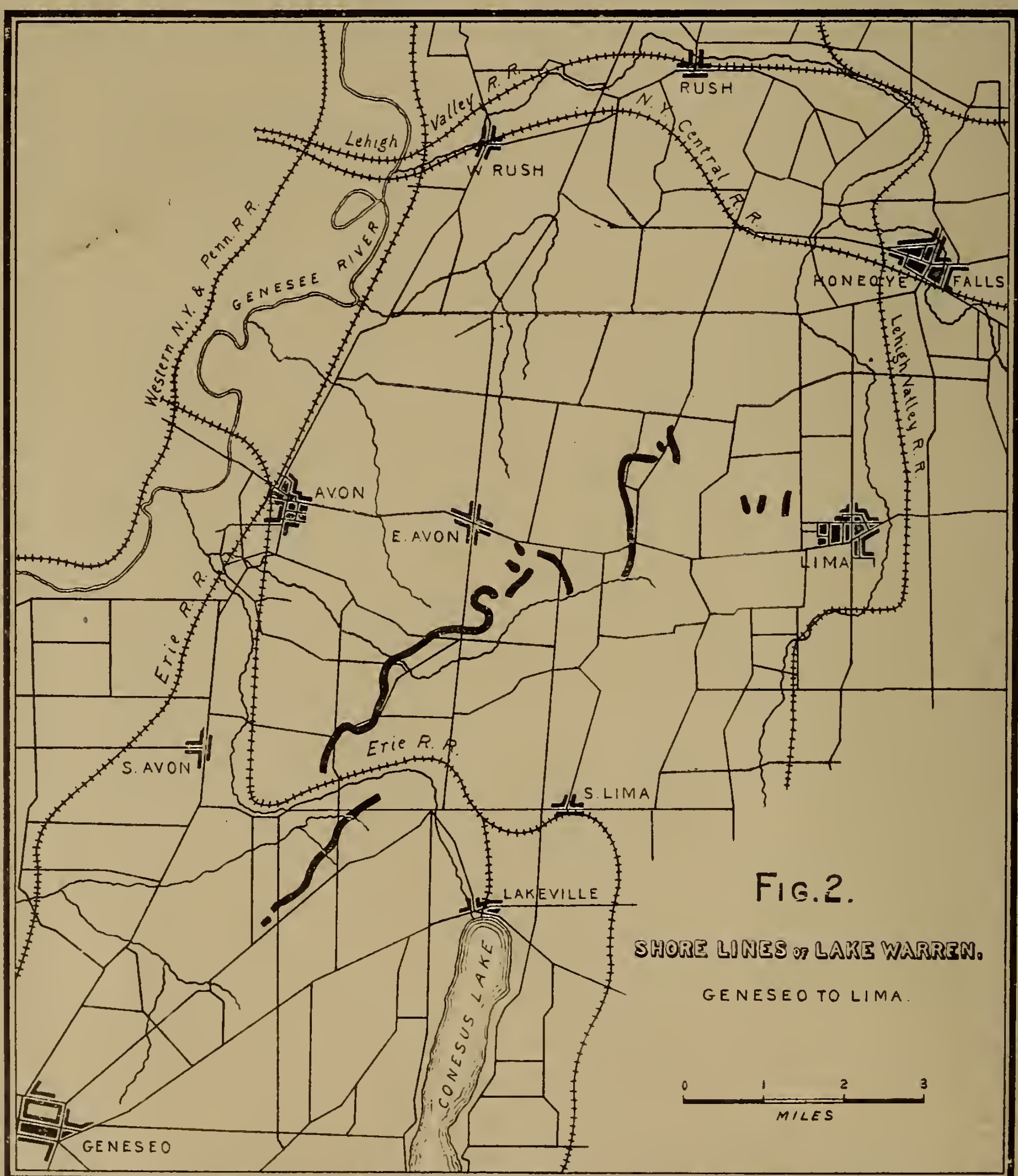


FIG. 2.

SHORE LINES of LAKE WARREN.

GENESEO TO LIMA.

LAKE WARREN SHORELINES IN WESTE

1.
LAKE WARREN.
CALEDONIA.

FIG.3.
GENEVA BEACH.

NEW YORK AND THE GENEVA BEACH

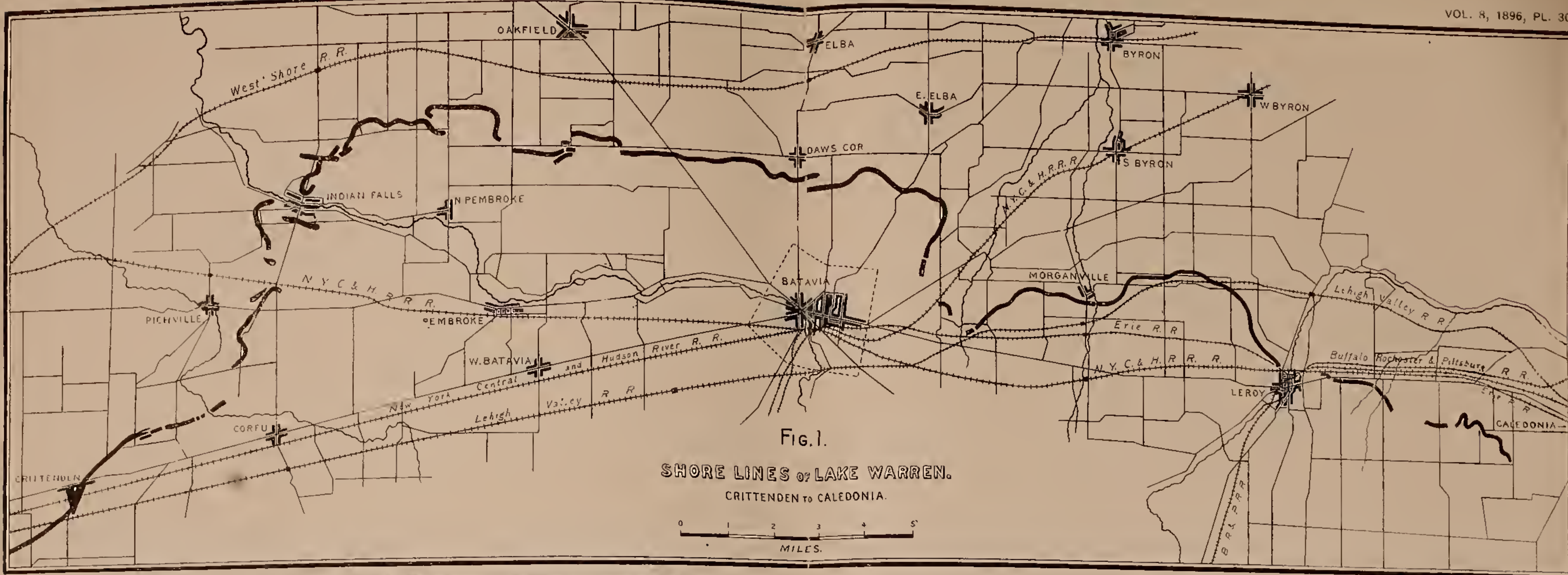


FIG. 1.
SHORE LINES OF LAKE WARREN.
CRITTENDEN TO CALEDONIA.

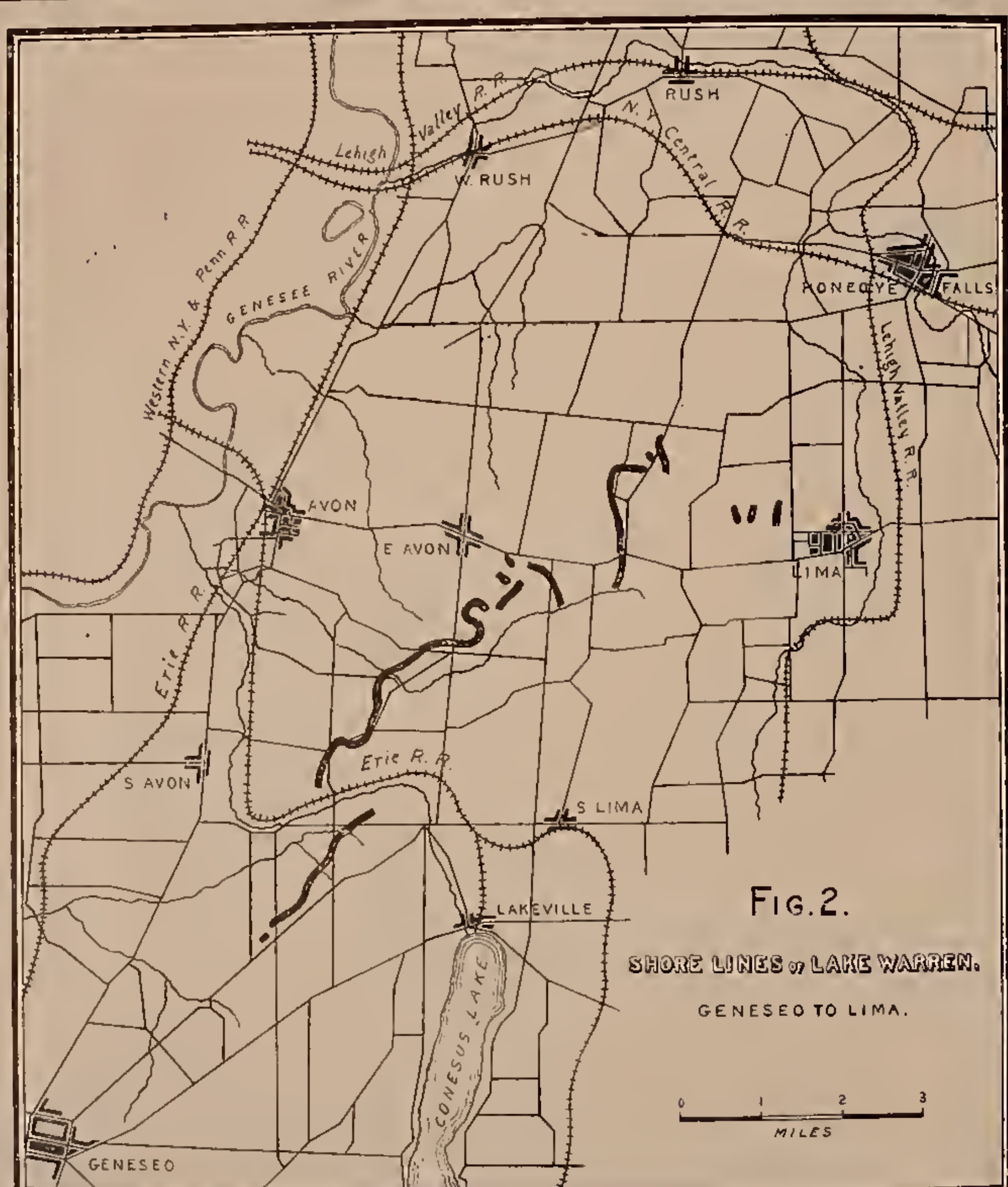


FIG. 2.
SHORE LINES OF LAKE WARREN.
GENESEO TO LIMA.

FIG. 3.
GENEVA BEACH.

LAKE WARREN SHORELINES IN WESTERN NEW YORK AND THE GENEVA BEACH

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LAKE WARREN SHORELINES IN WESTERN NEW YORK AND THE GENEVA BEACH

BY H. L. FAIRCHILD

(Read before the Society December 30, 1896)

CONTENTS

INTRODUCTION.

Lake Warren* is the name given by geologists to an extensive body of water held at a high level in a portion of the Laurentian basin by a barrier of glacial ice which blocked the low eastern outlets. The Laurentide continental glacier, which at its maximum covered all the upper Mississippi valley and the basin of the Great Lakes, had at this time receded so as to leave at least the southernmost part of the Laurentian basin exposed. The ice still lay over most of Canada and northeastern New York, and the water in the uncovered part of the basin being unable to escape by the Saint Lawrence or Mohawk valleys, these being still closed by the ice-sheet, was compelled to find an outlet to the sea by the Mississippi.

* The name was proposed by J. W. Spencer in an article in Science, vol. xi, January, 1888, p. 49, in honor of General G. K. Warren. The literature will be found mainly in the writings of J. W. Spencer, Warren Upham, and F. B. Taylor, in the American Journal of Science, American Geologist, and Bulletin of the Geological Society of America.

The glacial lake Warren is believed to have covered all of the basin of the present lake Erie, at least the southern part of the Huron basin, and some portion of the western and southern part of the Ontario basin. Until recently it was supposed that this water was broadly confluent with the glacial lake occupying the Michigan basin and probably a portion of the Superior basin, which latter lake had its outlet past the present site of Chicago through the Des Plaines and Illinois rivers to the Mississippi, and the name "Warren" was used to cover the entire expanse. Later researches by Mr F. B. Taylor* indicate that the water of the Michigan basin probably held a level somewhat lower than the water in the Erie-Huron basin, and that the latter found escape across the lower peninsula of Michigan by the Pewamo channel † and the valley of the Grand river to the lower lake. Possibly the waters in the two basins may have had nearly the same level and a connection by narrow strait similar to that of the present lakes Michigan and Huron. In either case the water in the Michigan basin requires a separate name, and the name "Lake Chicago" has been proposed by Mr Leverett and concurred in by the several geologists interested in this investigation (see page 52 of this volume).

In former publications the writer has referred to evidences of deep postglacial waters over the region of the Genesee valley and eastward and assumed the presence of lake Warren. Even without the proof from beaches the evidence of static water seemed sufficient. However, the working hypothesis held by glacial geologists favored the opening of the Mohawk outlet before the Ontario ice lobe retreated from the Lockport-Batavia highland. In such event the Warren waters, imprisoned in the Erie-Huron basin, would have been at once lowered toward the Iroquois level (Mohawk-Hudson outlet) by the withdrawal of the ice-dam from the Helderberg escarpment north of Batavia, and the Warren shoreline would not extend east of that high land. The first search for Warren beaches in the Genesee district was made in the spring of the present year (1896) and with immediate success. The first discovery was of the bars and spits near East Avon, which were traced eastward to Lima. Later the beach was found at Morganville, east of Batavia, and traced both eastward and westward. Finally the Warren beach at Crittenden was taken as starting point and traced northward past Indian Falls and about the tableland north of Batavia into connection with the shoreline already followed westward from Morganville.

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*See Correlation of Erie-Huron Beaches with Outlets and Moraines in southeastern Michigan, in this volume, pp. 31–58.

† References to this old channel are found in papers by J. W. Spencer, Am. Jour. Sci., vol. 41, March, 1891, p. 207; by E. H. Mudge, Am. Jour. Sci., vol. 50, December, 1895, p. 442, and by F. B. Taylor, in this volume, p. 52.

The morainic and lacustrine features of extreme western New York have been studied by Mr Frank Leverett and discussed by him in an article entitled "Correlation of New York Moraines with raised Beaches of Lake Erie." * Some of the views guardedly expressed in that article are definitely confirmed, while others require modification. The Lockport moraine was, undoubtedly, the eastern limit of the Warren water for a considerable time and correlates with the formation of the beach south of Crittenden, but the withdrawal of the ice-front from that portion did not produce immediate lowering of the water or terminate the beach-making process at the Crittenden level. The zone of sand and gravel drift described by Mr Leverett as lying north of the Lockport moraine (see page 19 of his article referred to above) is the shore-deposit of the enlarged lake and is definitely bordered by the eastward extension of the beach.

A comparison, as regards the time involved, of the beach east of Indian Falls with the beach westward is very difficult to make on account of the difference in the topographic relief. The Crittenden beach is much more mature, but it lies nearly parallel with the contours of a comparatively smooth sloping plain, and the conditions favored the rapid maturing of the shoreline. Eastward from Indian Falls the land surface is very uneven and the shoreline lies transverse to the drumlin molding, which conditions would require a much longer time to straighten and mature the beach. With all allowances, the impression made upon the mind is that of somewhat less duration of the beach-making forces in the Genesee region.

The altitude of the Warren beach from Batavia eastward indicates that the Warren plane must pass beneath the plane of the local lake held in the Seneca embayment and outflowing by the Horseheads channel to the Susquehanna river. Lake Newberry † was therefore not the successor of lake Warren, but, on the contrary, the latter robbed the Horseheads channel and succeeded lake Newberry in the Seneca region. The projection of the Warren plane northeastward would carry it about 500 feet above the Iroquois plane.

Evidences of a plane of static water lower than the Warren have also been referred to in former writings. During the summer of this year a strong beach was found near Geneva, about 170 or 180 feet below the Warren plane, and it has been traced north and west for many miles. This beach is evidence of a pause in the subsidence of the Warren water of length sufficient to constitute a beach-making period, or else it indicates a readvance of the ice over the Mohawk outlet and a distinct lacus-

* Am. Jour. Sci., vol. 50, July, 1895, pp. 1-20.

† Lake Newberry the possible Successor of Lake Warren. Bull. Geol. Soc. Am., vol. 6, pp. 462-466.

trine episode. In either case it adds an interesting fact to the history of the glacial waters in their fall from the Warren level to the final Iroquois stage, and at the present writing a puzzling fact, since the correlating outlet channel has not been found.

The special purpose of this writing is to place the following facts of observation on record in sufficient detail for others to find and observe the phenomena.

Maps.

The maps accompanying this paper, and which form figures 1, 2, and 3 of plate 30, are intended to indicate, by the heavy solid lines, the location of the beaches with reference to highways, streams, etcetera. It has not been practicable to show the character of the beach, whether cliff or bar or spit, but this is generally stated in the verbal descriptions in the text. In most cases the beach-lines represent well defined ridges or embankments.

Warren Shoreline.

FROM CRITTENDEN TO INDIAN FALLS.

One mile southwest of Crittenden the Lehigh Valley railroad crosses the beach obliquely by a cutting. This affords an accurate determination of the altitude of the beach, which at this point is 858 feet above mean ocean level.

The village of Crittenden lies upon the broad, low ridge of fine gravel and sand to which the name of the village was given many years ago by Mr Gilbert (see plate 30, figure 1).*

For over a mile going northeast the ridge is traversed by the highway, which then, turning more to the east, leaves the beach a short distance upon the northward for nearly two miles. West of the north-and-south county line road the beach has been wholly removed for a space by an extensive excavation by the New York Central railroad. East of the county line the beach is divided into two or more embankments, and is less definite for a fraction of a mile, but recovers its usual strength before reaching the next north-and-south road. The houses of Miss Hair and Mr John Brown are located upon the beach at the road intersection. One-third of a mile farther east the ridge suddenly terminates on the border of Murder Creek valley. Nearer the creek some knolls of sand occur, which may be fragments of the eroded beach. Beyond the creek or northward the ridge reappears, but is irregular, and soon disappears in a kame-moraine surface. Perhaps even here more thorough search will identify the beach-line. A wave-cut cliff may be seen further east.

The beach reappears about one mile north, near the intersection of two

* See F. Leverett: Am. Jour. Sci., vol. 50, 1895, p. 2.

roads, and is probably indicated in a forest by a gravel pit at the roadside. Passing northward, the shoreline lies west of the highway, along the western edge of a morainic area, for over a mile, or as far as the junction of this road with the east-and-west Richville-Batavia road. At this road junction the house and barns of Mr John Donovan stand upon the beach, which, as a fine, strong ridge, runs north-by-east for half a mile, and changes to a cliff about the northern edge of the moraine, near the Batavia-Tonawanda branch of the New York Central railroad (see figure 1). Another heavy ridge lies westward (lakeward) of the former, with a direction northeast by southwest. The northern ends of the two ridges nearly coalesce. North and east of the cliff, or north of the moraine, is a stretch of low ground which was covered by an embayment of the lake waters. Here the beach is interrupted for about a mile, but reappears due north as a heavy spit thrown eastward from the south end of a kame. Northward the shoreline skirts the west side of the kame and reappears at the north side of the kame as a very heavy ridge, which leads north along the east side of the north-and-south road; then, as a cliff-line, the beach lies in the road a short space, then crossing to west of the road it skirts the west side of a kame-moraine area and crosses an east-and-west road; thence swinging to the northeast it becomes a low, flat bar upon the very crest of the Corniferous escarpment, a mile west of Indian Falls village (see figure 2).

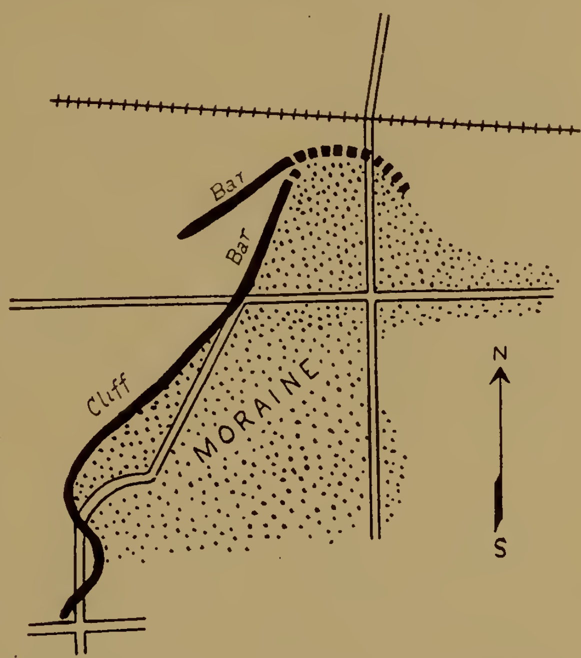

FIGURE 1.—*Beach Phenomena east of Richville.*

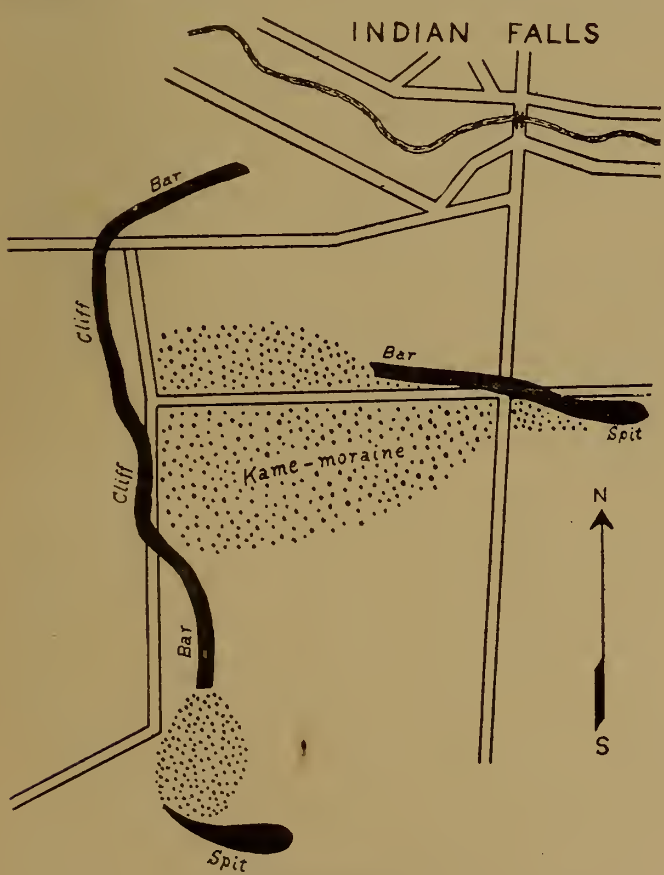

FIGURE 2.—*Beach Phenomena southwest of Indian Falls.*

The steep northern side of the kame-moraine, facing Tonawanda creek, has not preserved the shoreline features, but passing around to the east side a good bar and spit are found just south of the village. This has a direction south of east, touching the four corners made by intersection of the north-and-south, Indian Falls-Corfu, road by a local east-and-west road. The residence of Mr Otto Clark is at the corners. The shoreline follows the road east from the corners a few rods, then crosses to the south side of the road, and ends as a heavy, broad spit behind the German church. A cemetery is located upon the point of the spit. This forms the eastern extremity of the island made by the kame-moraine southwest of the village.

FROM INDIAN FALLS TO BATAVIA.

At Indian Falls the channel of Tonawanda creek interrupts the beach for three-fourths of a mile, but it reappears in excellent form on the summit of the hill at the north edge of the village. A strong ridge of somewhat angular gravel lies upon the east side of the road and supports the house of Mr C. T. Pratt. The southern end of this bar turns west, crosses the road, and then turning north runs along the west side of the road to a three corners. Here the bar swings eastward, crosses the road by the house of Mr Bascom, then curving northward passes behind the house of Mr Peter Lester. In a short distance the bar turns east, at which point another branch runs west, the latter crossing the road and terminating upon the crest of the Corniferous escarpment. The eastward branch soon breaks into a series of overlapping bars and spits of good development. Turning northward, in about one-half mile the beach crosses an east-and-west road, by which is an old gravel pit in the ridge, and soon drops over the edge of the Corniferous limestone a few rods east of a north-and-south road. For a short distance the shoreline is a cliff in the limestone, but quickly surmounts the escarpment as a well developed ridge of almost clear chert.

It is an interesting fact that the altitude of the Corniferous escarpment and the surface of the Warren waters were nearly coincident. From Indian Falls around to northeast of Batavia, a distance on the shoreline of perhaps 20 miles, the beach is usually on the crest of the rock ledge, as a ridge of nearly clear chert. At a few points the rock was higher than the water, and wave cut cliffs are conspicuous. The best cliffs are south of Smithville, east of Daws Corners, and northeast of Batavia.

From the point last mentioned in the detailed description the beach follows the irregular crest of the rock escarpment for two and one-half miles, crossing several highways, as shown in the map, and terminates behind a rock hill near a stone school-house at three corners. A strong, wave-cut cliff is seen upon the west end and north side of the hill, which is an outlier of the Helderberg-Corniferous strata. About a mile west of the north-and-south, Smithville-Pembroke, road the shoreline again becomes a ridge upon the drift-covered escarpment. The beach then runs due south one mile, and after some interruption in a kame area crosses at four corners to the south side of the east-and-west town-line road and stretches along the north side of a moraine for about one mile, when it breaks into several bars. Another very heavy ridge is found one-fourth of a mile north on land of Mr Weber Stevens, in an old orchard on the east side of an old road. This ridge of gravel runs east and southeast one mile. At the next north-and-south road, leading south from Oakfield station on the West Shore railroad, the shoreline is a cliff in till, but soon resumes its normal character as a strong ridge of chert gravel along the south side of the east-and-west town-line road. For three miles the beach, as embankment or cliff, runs parallel with the road, close upon the south side, against the north side of the moraine or drift-covered terrane. It is generally 25 or 30 feet above the highway, which lies upon the lake floor, the latter stretching north as a smooth plain.

About a mile west of Daws Corners the strong bar curves southeast, then after a gap by stream erosion it swings by curves eastward to the Elba-Batavia road, which it crosses about one-half mile south of Daws Corners, close to the house of Mr Sylvester Strong. The bar, which here is destitute of chert, ends about one-half mile east of the road in a heavy spit, on the edge of a broad stretch of low ground. A wave-swept plain of sand borders the depression on the north, with low spits running into the depression.

One-third of a mile south the shoreline is conspicuous as a bold cliff in the east and west escarpment. Running eastward one-half mile, it becomes a bar and then makes a curve to northward, lying on the summit of the high, steep escarpment of the Helderberg, about one-third of a mile south of the town-line road. At the extreme northern point the shoreline lies just beneath the very top of the escarpment, which is Corniferous. From this point the beach runs southeast one mile to the northeast-southwest road, at which point the ridge has been excavated for gravel. Here it is on the top of the escarpment as a good ridge, and so continues eastward for one-half mile, when it falls below the crest of the ledge and curves around to southward as a rock cliff for nearly two miles. The shoreline crosses to the east side of the north and south town-line road, then after running along the road for about one-fourth of a mile it lies in the roadway for about the same distance, then recrosses to the west side, and in half a mile becomes a well developed gravel ridge. In the ground of Mr Charles Thornwell it bears a gravel pit, visible from the highway. Near the gravel pit the bar has been cut by drainage, and south of the gully a fine ridge is found, with north-and-south direction, on the land of Mr J. Miner. This is about two and one-half miles northeast of the center of Batavia village.

FROM BATAVIA TO CALEDONIA.

East of Batavia village the moraine, with strong relief, lies partially below the Lake Warren level. The lake waters were here entangled among the hills and the beach is broken for two miles, but two well defined wave-cut cliffs are conspicuous. These are clearly seen from the main line of the New York Central railroad, which, eastward from Batavia, traverses the moraine and descends rapidly upon the silt plain formed as the floor of the Warren waters. The more westerly cliff is upon the north and east side of a till ridge about one mile southeast of the bar last mentioned and about one-fourth of a mile east of the railroad. Well defined but broken shore phenomena connect this cliff with another cliff in drift one mile further eastward. The beach then runs northeast another mile as a good ridge to a strong cliff in Corniferous limestone, which shows excellently the effects of heavy wave action upon a headland. From this cliff a nearly continuous bar or ridge is found for the six miles to Le Roy. The accompanying map will show the direction and location of the beach better than verbal description.

The beach passes through the southern and higher part of the village of Morganville and shows in good form both east and west of the village. The altitude of the beach is here definitely known. One and one-half miles northeast of Morganville and about half a mile west of schoolhouse number 3 is a station of the United States Lake Survey, located exactly upon the beach ridge, with a corrected altitude for surface of the ground of 880 feet. Upon the west side of the north-and-south road, by school number 3, which is situated upon the beach, the crest of the beach is 4.56 feet under the top of rail of the Lehigh Valley railroad at the road crossing one-fourth of a mile south. The altitude of rail is 884.60, making the crest of beach 880 feet. One-half mile farther east the railroad crosses the beach by a cutting, and the altitude is 879 feet.

Approaching Le Roy, the beach becomes obscure upon a kame-like surface among low drumloids about one-half mile northwest of the railroad stations. The level of the water-surface passes through the lower or northern part of the village. The next appearance of the beach is a good gravel ridge about one mile east of the village, between the LeRoy-Caledonia highway and the three railroads, on the land of Mr A. H. Olmstead. The ridge curves around northeast of the farm-house and barns and once formed a hooked spit near the highway, which has been cut away for gravel.

Across a brook and upon the south side of the highway the beach reappears in excellent form as a heavy gravel ridge beneath the residence of Mr Abram Van Valkenburgh. For about a mile the ridge follows along the south side of the highway, slightly diverging and giving location for the residences upon that side of the road.

Eastward from here the ground is lower and with long, drumlin ridges. The shoreline is exceedingly crooked and the beach phenomena obscure in the embayments, but usually pronounced at the north ends of the ridges. The map (plate 30) will show approximately the location of the observed shorelines and the distinct gravel ridges. At the crossing of the north-and-south ("old Phelps") road the ridge bears the house of Mr Patrick Conlon.

Within three miles of Caledonia the shoreline is thrown rapidly southward upon the west side of the Genesee Valley embayment, and has not been traced farther than is shown upon the map.

THE GENESEE EMBAYMENT.

The Warren waters occupied the valley of the present Genesee river as far south as Mount Morris. The accumulation of sand and silt either side of the gorge ("High Banks") west of the village doubtless represents the delta deposits of the stream during the Warren episode, before the gorge was excavated. The waters occupied the preglacial valley of the river, now possessed by the Kishawa creek, as far as the village of Nunda, and numerous terraces and plateaus in that valley are thought to represent the work of those static waters. The lower Canaseraga valley (Dansville valley) was flooded to its head, some four miles south of Dansville. About the head of this valley a succession of terraces indicate the levels of the subsiding waters,* and some of the lower terraces will undoubtedly correlate with the Warren beaches.

The valley of Conesus lake was also occupied by the Warren waters, which found access by the depression along the present outlet north of the lake.

The Warren waters in the Genesee embayment were several miles in width and of considerable depth, and it is possible that with sufficient search the shores may be located at various points, even as far south as Dansville.

FROM GENESEO TO LIMA.

The ground east and northeast of Geneseo is thrown into a series of fairly strong drumlins over Hamilton shales. The ridges are generally

* For a map of the Genesee valley and discussion of the lake history, see Bull. Geol. Soc. Am., vol. 7, pp. 423-452; also vol. 6, pp. 358-361.

a stiff till, with direction west of south and roughly parallel to the Genesee valley, of which they form the east slope.

Four miles northeast of the village of Geneseo good shoreline features have been found. Opposite the house of Mr Samuel Cully, on the west side of a north-and-south road, is a stony drumlin which has had the north end cut away and the material swept eastward into a curving spit which nearly spanned the adjacent hollow. This spit now has a length to the stream gully of 40 or 50 rods, with a width of 10 to 15 rods.

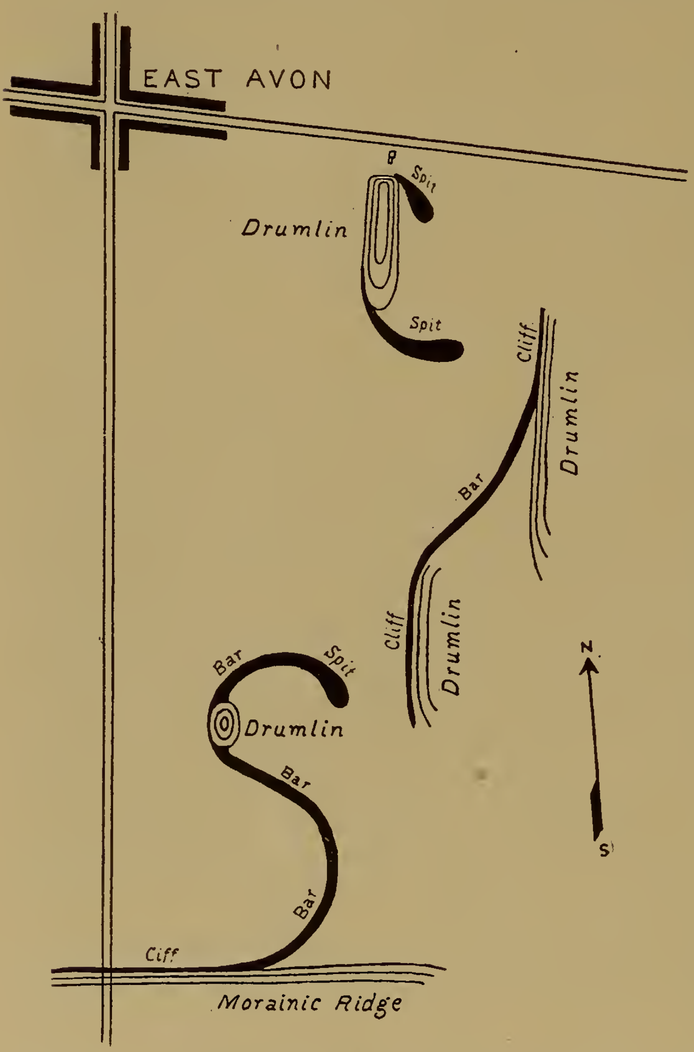

FIGURE 3.—*Beach Phenomena south of East Avon.*

A short distance northward, on the west side of the same highway, a neat bar of clear gravel occurs opposite the house of Mr James Weeks. From this point the shoreline follows the west slope of a drumlin for about a mile in a northeast direction. At a small creek it forms a good gravel ridge, and so continues for another mile, crossing a stream and two highways (one being the east-and-west town-line road) just east of their intersection. This line of beach formation ends a quarter of a mile north of the road on the edge of the Conesus outlet valley.

Across this narrow valley (which is followed by the Erie railroad), over one-half mile to the west of the point last mentioned, the beach reappears as a cliff-line, but becomes a fine ridge at school number 5, at another four corners. A gravel pit may be seen here revealing beach structure. The beach follows the road leading northeast, crossing to the east side, then in one-half mile recrossing to the west side, under the house of Mr Seymour Johnson, at the forks in the road. For a quarter of a mile it follows along the west side of the northern road, then diverges and soon crosses an east-and-west road under the house of Mr John Hooker. Turning northeast, in about three-fourths of a mile it crosses another east-and-west road under the house of Mrs William Davis; then as a cliff-line it soon crosses the north-and-south, East Avon, road and changes to the beautiful series of ridges and hooks one mile south of East Avon (see figure 3).

The East Avon beaches lie at the southeastern edge of the wave-swept plain upon which East Avon is situated. The bars and hooks are from 10 to 20 rods wide at the base, 15 to 20 feet high, and of perfectly uniform altitude. Where they disappear against the sides of the drumlins the wave-cut cliffs are very evident. This system of curving ridges and cliffs terminates at the north in a broad lobed spit formed at the north end of a drumlin in the rear of the residence of Mr Cortez Landon. This is upon the south side of the Avon-Lima road, about one-half mile east of East Avon village. Mr Landon's house is placed upon the shelf cut out of the drumlin by the waves.

A line of instrumental levels was run from Avon station on the Erie railway. Taking the top of the west rail of the Erie railroad at the Avon highway as 583.3 feet, the height of the spit behind Mr Landon's house was found to be 873 feet.

Eastward upon the Lima road a short but clear beach is seen extending from the north end of a drumlin. The house of Mr A. G. Bristol is located at the eastern end of the beach. In the adjacent field eastward, owned by Mr James Bristol, the beach is again found as a short, broad, gravel bar, and shows still more clearly southeastward, crossing the north-and-south highway, at which point an old abandoned house is located upon the beach. Across the north-and-south hollow the shoreline features are clearly seen upon the eastern slope.

Passing northward along the shoreline it appears as a well marked erosion cliff in a drumlin ridge, which at its north end, within about one-fourth of a mile of the east and west Avon-Lima road, has a distinct shelf cut by the waves and the debris built into a strong bar. This bar is on land of Mr Walter Sherman. It has a direction a little east of north and strikes the Avon-Lima road at the junction of a road from the north, about one-half mile west of the town line. The bar has been cut by a small stream, but is otherwise continuous at the full height of the beach. It is about 25 feet high on the landward slope.

The shoreline runs along the western or lower side of the road which leads north upon the west side of a huge drumlin, locally known as "Huckleberry hill." The beach gradually diverges from the road, and in about three-fourths of a mile it develops a strong bar which strikes another road, branching westward from the first, exactly where the branch road makes a right angle from westward to northward. As an erosion line the shore can be traced northward along this road for half a mile, when it curves eastward, crossing the road, and cuts the north end of a drumlin. Then as a heavy ridge, at least 15 rods wide at base and 25 feet high, it runs eastward about one-half mile on land of Mr Charles Hovey and ends abruptly as a broad spit close by the west side of the Huckleberry Hill road.

A few rods north of the end of the spit and across a narrow valley is another spit, formed at the south end of a drumlin, in which is a gravel excavation. Another heavy ridge springs from the eroded north end of the drumlin and runs southeast, crossing the road, and terminates indefinitely in steep banks, perhaps 80 feet high. These phenomena are shown in figure 4.

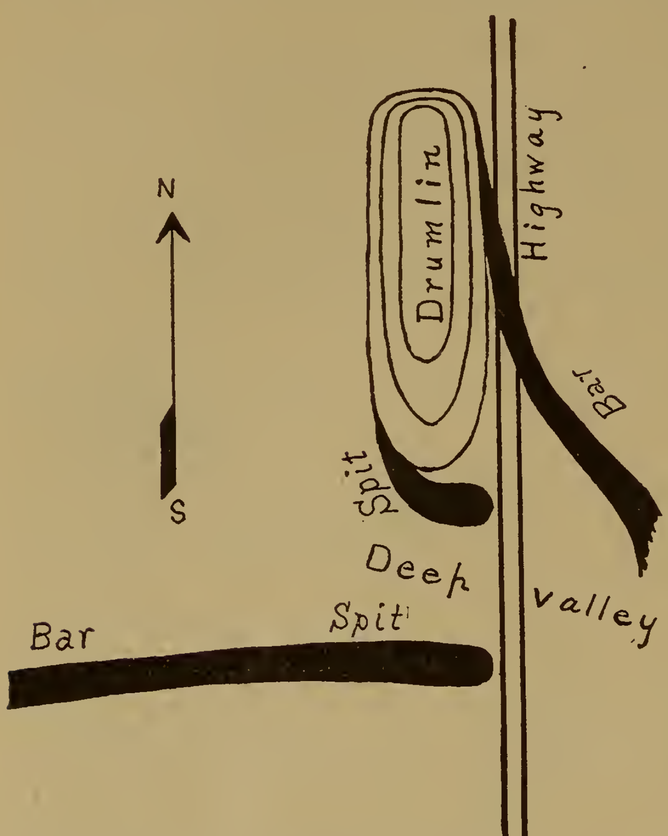

FIGURE 4.—*Beach Phenomena northeast of East Avon.*

The ground to the eastward is molded into drumlin ridges at such an altitude as to break the shoreline into a series of long, narrow, shallow bays and to prohibit heavy wave action. Bars and spits occur at the north ends of the ridges and rarely in the embayments.

An example is given in figure 5, which represents an area about one mile northwest of Lima village, where in a north-and-south drumloidal valley having a gentle northward slope the low embankments are located symmetrically upon opposite sides of the valley, converging southward and ending as spits. The western slope is land of Mr William Vary; the eastern belongs to Mr Wilkeson Cary.

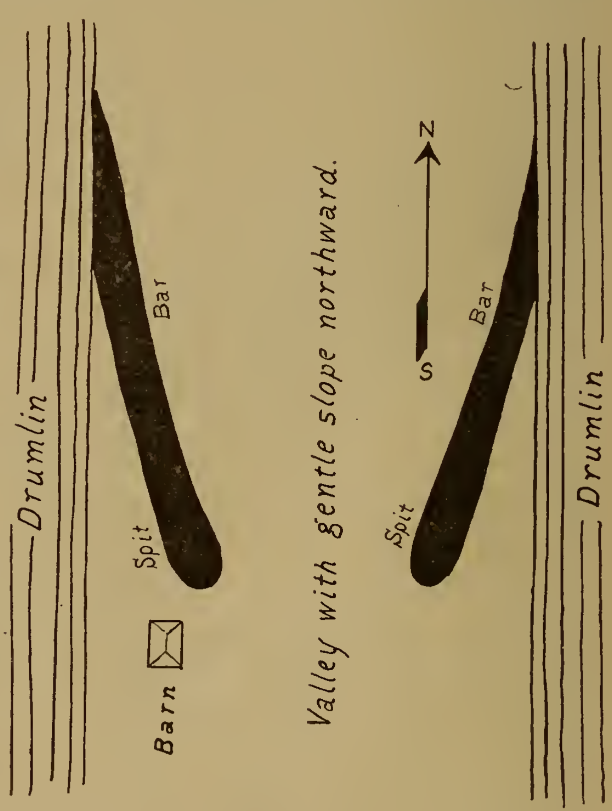

FIGURE 5.—*Beach Phenomena in Valley northwest of Lima.*

Another well defined gravel beach is found farther east upon the slope facing Lima. The altitude of this beach is, by Lehigh Valley datum, 877 feet. The ground then becomes lower and so broken and morainic that the shoreline phenomena are obscure. The village of Lima is upon a moraine at the lake altitude. The shoreline passes through the village as an irregular and undetermined line, then swings to the south along the west slope of the broad but shallow Honeoye valley.

EAST OF LIMA.

The beach one mile west of Lima is the most easterly point of the shoreline that has been positively identified. Examination has been made farther east in the hilly region of West Bloomfield and East Bloomfield; also between Canandaigua and Seneca lakes, but without finding any unmistakable beaches that might not belong to other waters. The evidences of static water are sufficient to prove the presence of the lake, and beaches may yet be discovered. In the Seneca embayment some shore phenomena are thought to have been found, but having an altitude somewhat over 900 feet are believed to correlate with the local lake having its outlet at Horseheads to the Susquehanna waters.*

Geneva Beach.

GENERAL DESCRIPTION.

This name is applied to a newly discovered shoreline of strong development. It occurs in its best form upon the western slope of the Seneca valley, and from Geneva pursues a nearly direct line north by northwest for about 7 miles to a point 2 miles south of Phelps. The beach phenomena are very strong and characteristic, being chiefly wave-cut cliffs on drumlin slopes, but showing several heavy bars and spits. The phenomena as a whole are quite as strong as those of the Warren beach east of Indian Falls.

From Phelps westward the shoreline is transverse to the drumloid molding of the region and the beach is in consequence broken and irregular and often obscure. It has, however, been clearly traced westward 6 miles from the point south of Phelps, or to within about 2 miles southeast of Shortsville. This carries the beach around into the Canandaigua embayment and indicates that it belongs to a water body more extensive than one restricted to the Seneca embayment.

The altitude of the beach at Geneva is just 700 feet, and near Phelps it seems to be 10 or 15 feet higher. It is believed by the writer that this beach correlates with the terraces and plateaus of static water origin in the Irondequoit valley, which have been merely mentioned in former writings.† Indeed the evidences of this water-level have been seen upon the Mendon kame hills and upon the drumlins as far west as the Genesee

* Bull. Geol. Soc. Am., vol. 6, pp. 365–369, 462–466.

† Kame Areas in western New York, etc., Jour. of Geol., vol. iv, p, 135.

river, and one spit has been found at Victor. The outlet of the lake held at this level is unknown.

DETAILED DESCRIPTION.

The following detailed description will enable any one to verify the writer's observations:

The point where the Geneva beach was first seen, and which may be taken as the starting point for description, is about 2 miles southeast of the center of the town, at the intersection of the north and south "Preemption road" by the east-and-west Flint-Geneva road. The beach lies exactly at the crossing, having a direction northwest-southeast. Southward it passes along the east side of the Preemption road, showing as a ridge or bench of gravel on the drumloid slope.

Northward of the corners the beach passes beneath the house and barns of Mr Charles Bean. Beyond the buildings it forms a fine ridge of clear gravel 10 to 15 feet high on the landward side and as many rods wide at the base.

Taking the top of rail of the Lehigh Valley railroad at the Preemption crossing, one mile north, as 606.92 feet, the crest of the ridge is just 700 feet above tide.

The ridge curves to westward and fades out in one-fourth of a mile in a narrow depression of the land surface, but reappears upon the opposite slope as a low gravel bar. Along the east slope of the drumlin ridge the shoreline is evident for a mile, mainly as cliff on the till slope, and indicating long continued heavy wave-action. The first interruption is by a creek channel used by the Naples branch of the Lehigh Valley railroad. North of this break the beach reappears as a good ridge, terminating in about a mile as a secondary or lakeward bar. Landward another ridge appears, which soon changes to a strong cliff on the east slope of a drumlin. Either as cliff or gravel embankment, the beach follows the east slope for one and one-half miles, crossing the Seneca Castle road and following along the east side of the stretch of road having a northwest-southeast direction. Where the beach leaves the northern angle of that road it is a heavy ridge. The large barn of Mr William Kane is located upon the beach.

The heavy ridge last mentioned ends one-half mile north of the Seneca Castle road, on a border of low ground. Across the low space the beach forms a cliff on the east and north sides of a drumlin and changes to a heavy, broad spit on the west side of the north-and-south road, at the edge of another narrow valley. An old brick house belonging to Mr George Johnson stands by the highway just above the shoreline.

The beach is interrupted for about one-fourth of a mile, and reappears on the east side of the north-and-south Phelps road as a low bar south of the house of Mr W. D. Burnett. For two miles the beach follows along the east side of the highway; the first mile as a cliff or gravel shelf, then for one-half mile as a heavy ridge of gravel. At the four corners, by number 2 school, the beach is a steep cliff, and so continues for another half mile, until it swings west, crosses the road, and forms a strong ridge by a reservoir. Here the ridge has been cut by erosion, but is continued northward with great strength for a short distance, when it becomes a cliff on an eastern slope. A quarter of a mile east or lakeward of this cliff is a heavy ridge, possibly drumlin, surmounted by a gravel deposit for a length of perhaps one-third mile, ending very abruptly at the north end. The ridge and the cliff seem to be connected by a transverse bar.

The beach-line passes around the north end of the western drumlin ridge as a steep, eroded slope, with good cliff profile. On the west side of the drumlin is a gravel shelf. A heavy bar crosses the valley, cut by a stream, and has been excavated for gravel behind a barn on the east side of the north-and-south road. The shoreline passes north and very soon crosses the road and bends sharply around the north end of a narrow drumlin ridge, then less abruptly around the north end of another drumlin into a valley which interrupts the shore features for one-half mile. West of a brook is a gravel plateau, apparently somewhat under the water plane, and holding a gravel pit. Close to the north-and-south road, upon the east side, is a fine gravel bar supporting the house of Mr Edwin Ferguson. This lies opposite the junction of a highway leading west. Another ridge occurs at the road junction upon the west side of the road.

Here the beach is interrupted by the narrow gorge of Flint creek. The shoreline phenomena have not been closely searched upon the west side of the ravine. A poorly developed gravel bar was seen at the four corners by a school-house, and a strong gravel ridge occurs one-half mile west, in the southwest angle of four corners.

One-fourth mile further west is a high drumlin ridge, which is deeply cut by gullies down to the level of the beach-line. The latter passes about the northern end of the high ridge upon which is located the Clifton Springs reservoir. Upon the west side of the ridge and east of the road is a stretch of gravel which marks the water-level. The average of two nearly concurrent aneroid observations, made at different times by connecting with the Lehigh Valley railroad one mile north, gave an altitude of 711 feet.

Across the road and westward is low, swampy ground and only faint evidence of water-action is found, but one-half mile west occurs a good bar, of fine gravel, crossing a north-and-south road one-fourth of a mile south of the junction with the east-and-west town-line road. The phenomena are fragmentary for nearly a mile, owing to the irregular surface and stream erosion, but are as good as might be expected under the conditions. West of a small stream a good ridge is found, which swings around to the southward and is terminated by stream-cutting at an east-and-west road. The beach then follows a low slope westward, lying along the south side of the east-and-west road, crossing the north and south road, and is a good bar at one point. The phenomena terminate in an area of sharp, kame knolls at a road crossing about two miles southeast of Shortsville. The kame knolls were mostly submerged, but the high points were 40 to 50 feet exposed.

North and northeast of the district last mentioned the ground is thrown into drumlin ridges higher than the water plane, and the waters were not able to produce heavy beach phenomena.

West and southwest of the kame area the ground is too low for beaches, being a plain of till and clay with an average altitude of about 675 feet, but falling toward the valley of Canandaigua Lake outlet. The lake waters here formed an embayment, which included the valley of the present Canandaigua lake. The shoreline phenomena are to be looked for above Chapinville and about Canandaigua.

The total length of the beach as traced is from 16 to 20 miles.

The waters which produced this shoreline were not limited to the Seneca embayment, as the western end of the beach line faces lower ground toward the west, which reaches beyond the Genesee river. Moreover, there are evidences of the same water body in the Irondequoit and Genesee valleys. At Fishers and Victor are fine terraces and plateaus of undoubted static water origin, with an altitude of about 700 feet.

Near Victor one short bar or spit has been seen at about the proper altitude, but it has not been accurately measured. In Rush township, along the Genesee river, the north end of the drumlins are clearly notched by wave action at a corresponding height. Beach phenomena have not been seen in the Genesee valley, but will probably be found when carefully looked for.

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OLD TRACKS OF ERIAN DRAINAGE IN WESTERN NEW YORK

BY G. K. GILBERT

(*Read before the Society December 30, 1896*)

[*Abstract*]

The lowest water-plane of the glacial lake Warren was about 500 feet higher in the region of their overlapping than the plane of the next important glacial lake, Iroquois. Lake Iroquois drained eastward, and, as recently shown by Taylor, lake Warren drained westward. In the epoch between the two water stages the water plane was gradually but not continuously lowered by the discharge of water eastward across western New York. This discharge followed successively several different lines, which were roughly parallel with one another, but cut the lines of modern drainage at right angles. Each line was characterized by a succession of glacial lakelets occupying north-south valleys, and the lakelets were connected by rivers traversing the intervening uplands. The channels of the rivers are conspicuous topographic features, having in general the character of troughs, which in drift are from 1,000 to 2,700 feet broad and in shale from 350 to 700 feet. The coarser part of the material excavated in the formation of a channel is usually found in a delta deposit at its eastern end. At various points are cliffs over which the water plunged in cataracts. There are some channels with but a single wall, the opposite wall having been constituted by the ice-front.

One of the earliest of the channels heads a few miles south of Halfway station, 14 miles west of Syracuse, and is deeply carved in Hamilton shale; its intake has an altitude of 812 feet. An important channel of later date runs from Fort Hill, north of Le Roy, to Scottsville, and is occupied in part by Oatka creek. Another extends from East Rush to Mendon; is there interrupted by the Irondequoit valley; is resumed near Victor; discontinued near Coonsville; resumed again at Elbridge, and continued to Fairmount. Yet another extends from Fairport to Lyons. South of Syracuse are three channels, quite close together, one being traversed by the Delaware, Lackawanna and Western railroad, and thence westward to Mycenæ the system is somewhat complex. Most of

the drainage lines end at the Iroquois shore, but others terminate, so far as traced, at higher levels, indicating that before the establishment of lake Iroquois there was in the eastern part of its basin a higher base-level, probably determined by an ice-dam in the lower Mohawk valley. Near Syracuse certain of the channels are clogged by glacial drift in such way as to demonstrate a readvance of the ice after their formation by running water.

As the positions of details of the channels were determined by the relation of the ice-front to the configuration of the northward sloping land, their mapping aids in determining the trend of the ice-margin, and this trend is shown to have been approximately east and west in the Rochester-Syracuse region.

West of Clarendon the valley between the outcrops of the Niagara and Corniferous limetones appears to have held a shallow lake just after the retreat of the ice from the Niagara escarpment, and this lake initially discharged over the escarpment at five points—Clarendon, Shelby, Gasport, Lockport, and Niagara. The controlling sill on the line of Niagara river was at the Johnson ridge. Most of these overflows were of brief duration, but that at Lockport continued for a considerable period, competing with the Niagara for establishment as the permanent outlet of lake Erie.

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AGE OF THE LOWER COALS OF HENRY COUNTY, MISSOURI*

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(*Read before the Society December 31, 1896*)

CONTENTS

INTRODUCTION.

The studies on which the following somewhat epitomized discussion is based were prosecuted with the purpose of ascertaining, so far as the available data will permit, the comparative age of the basal coals of the Lower Coal Measures of Henry county, Missouri, and their approximate stage in sections of the Mesocarboniferous in other typical areas. The materials used are taken from a more extended work on the floras of the Lower Coal Measures of Missouri, in which the systematic treatment of the species involved in the present problem will be found.

The plants so abundantly gathered from the lower coals of this region may be regarded as typical of this zone in the trans-Mississippi area;

* Published with the permission of the Director of the U. S. Geological Survey.

and, since the Lower Productive Coal Measures of the more eastern states is, paleobotanically, by far the best known portion of the sections, the material in hand is better adapted to immediate correlative comparisons with the Coal Measures floras in the eastern basins than is that from a higher stage.

Local Stratigraphy of the Coals.

SOURCE AND NATURE OF DATA EMPLOYED.

In Henry county, Missouri, the Lower Coal Measures is said to rest on a deeply eroded Mississippian (Eocarboniferous) floor strewn with chert and other debris from the Saint Louis limestone or other members of that series. The lowest coal-bearing shales lie in erosion pools, estuaries, or ponds, and are disposed as filling or levelling material along the shores of the encroaching Carboniferous sea. The series is accordingly in general thickest over the lower portions of the floor, thinning out against the contemporaneous barriers and ridges. The greater part of the botanical material in hand is obtained at several localities in the region of Clinton, from what is described in the numerous published sections* of this series as the "Jordan coal." The remainder comes from the second higher seam, about 45 feet from the Jordan coal, on the Grand river, near Gilkersons ford. Both of these beds are included in the Lower Coal Measures of the earlier state reports or in the lower part of the "Des Moines," as proposed by Keyes.† Generally a thin and very irregular "ferruginous sandstone," the "Spring River sandstone" of Jenney, intervenes between the coal-bearing shales and the Eocarboniferous bottom.‡ In this region the plant-bearing horizons nowhere exceed an interval of 100 feet above the sandstone, while at some points they come in contact with its uneven surface. This sandstone, which is regarded as "Millstone grit" by the Missouri geologists, and whose more eastern representative was included in the Chester by the geologists of Illinois, appears rarely to be entirely absent locally, in which case the lower coals practically abut against the old shore.

RELATION OF AGE OF THE COALS TO EARLY MESOCARBONIFEROUS EPEIROGENIC MOVEMENTS IN MISSOURI.

The trans-Mississippi epeirogenic movements of the Carboniferous

* Broadhead: Rep. Geol. Survey of Missouri, 1872, part 2, pp. 6, 7, 16, 82, 88; Rep. Geol. Survey of Missouri, vol. viii, 1895, pp. 360–369. Winslow: Preliminary Report on the Coal Deposits of Missouri, 1891, p. 139, fig. 97; p. 141, fig. 99; p. 140, fig. 98.

† American Geologist, vol. xviii, 1896, p. 23; Report Geol. Survey of Iowa, vol. i, 1893, p. 85.

‡ The age of this sandstone, which, it would seem, may possibly in part represent the work of the encroaching sea in assorting the subaerial Mississippian debris, has not, I believe, been determined from paleontologic evidence.

epoch have been specially discussed by Hall,* Winslow,† Broadhead,‡ and Keyes.§ From the observations of these geologists it appears that in this region the early Mesocarboniferous time was marked by a general subsidence, the result of which was the concealment of the earliest Coal Measures strata by the overlaps of the succeeding terranes. The plants from these fossiliferous beds fringing the old irregular shore, with which in places they came in almost direct contact, mark therefore the time when the incursion of the Mesocarboniferous sea overwhelmed the vicinity of Clinton. Thus they serve as criteria for the approximate determination of the close in this district of that period of post-Mississippian erosion.

Composition of the Flora.

The examination of the plant collections from the coals under consideration reveals a flora of 123 species,|| the general characters and systematic range of which will be seen from the following abridged generic synopsis :

Fungi :
- *Hysterites*, 1.
- *Excipulites*, 1.

Ferns :
- *Eremopteris*, 2.
- *Pseudopecopteris*, 2.¶
- *Mariopteris*, 4.
- *Sphenopteris*, 19.
- *Oligocarpia*, 3.
- *Pecopteris*, 13.
- *Brittsia*, 1**.
- *Caulopteris*, 2.
- *Megaphyton*, 1.
- *Aphlebia*, 8.
- *Alethopteris*, 2.
- *Callipteridium*, 5.
- *Odontopteris*, 1.
- *Neuropteris*, 5.
- *Dictyopteris*, 1.
- *Tæniopteris*, 1.

Calamarieæ :
- *Calamites*, 3.
- *Asterophyllites*, 3.
- *Calamostachys*, 1.
- *Annularia*, 3.
- *Macrostachya*, 2.
- *Radicites*, 2.

Sphenophylleæ ;
- *Sphenophyllum*, 4.
- *Volkmannia*, 1.

Lepidodendreæ :
- *Lepidodendron*, 5.
- *Lepidophloios*, 2.
- *Lepidostrobus*, 3.
- *Lepidophyllum*, 2.
- *Omphalophloios*, 1.**

Sigillarieæ :
- *Sigillaria*, 4.
- *Stigmaria*, 2.

* Am. Jour. Sci., vol. xxvii, 1857, p. 197.

† Bull Geol. Soc. Am., vol. 3, 1892, p. 109–121 ; Am. Geologist, vol. xv, pp. 81–89 ; Preliminary Report on Coal, 1891, p. 19.

‡ Am. Geologist, vol. xiv, 1894, pp. 380–388.

§ Am. Geologist, vol. xii, 1893, p. 100.

|| Since most of the species found in the shales over the higher coal are identical with those found in the lower coal, as might be expected from the proximity of the two horizons, the combined species will be regarded as one flora in the present comparisons, in which only the general stage of the floras is considered.

¶ Emended and redefined.

** New genus.

TÆNIOPHYLLEÆ:
- *Tæniophyllum*, 1.
- *Lepidoxylon*, 1.

GYMNOSPERMS:
- *Cordaites*, 2.
- *Cordaianthus*, 2.
- *Cordaicarpon*, 1.

GYMNOSPERMS:
- *Cardiocarpon*, 1.
- *Rhabdocarpos*, 2.
- *Titanophyllum* (?), 1.
- *Dicranophyllum*, 1.

ANIMALIA (?):
- *Palæoxyris*, 1.

From the above epitome it will be noted that most of the commoner Mesocarboniferous plant genera of the world are present in the lower coals of Henry county. The ferns are especially preponderant, while the Sigillarieæ are comparatively poorly represented. The relatively large number of species of *Pecopteris* is notable, although two or three of the latter, including those which are generally regarded as indicating a higher zone than that in which some of the forms of *Pseudopecopteris* and *Mariopteris* are common, are extremely rare.

DISTRIBUTION OF THE SPECIES IN OTHER AMERICAN BASINS.

Of the plants included in the foregoing summary, a portion * are new or have not been found in other regions, and therefore offer only inferential and subordinate correlative aid, such as may be cautiously drawn from their biological relations or the distribution of the species to which they appear to be most closely related.

Another category of species of little definite help in chronologic studies includes those having a wide vertical range. Examples of such are *Pecopteris dentata*, Brongn.; *Neuropteris scheuchzeri*, Hoffm.; *Neuropteris rarinervis*, Bunb.; species of *Calamites; Asterophyllites equisetiformis*, (Schloth.) Brongn.; *Annularia stellata*, (Schloth.) Wood; *Annularia sphenophylloides*, (Zenk.) Gutb.; *Sphenophyllum emarginatum*, Brongn.; *Sigillaria tessellata*, (Steinh.) Brongn., and *Rhabdocarpos multistriatus*, (Presl) Lx., although several of these species are found on examination to be clearly differentiated in forms or varieties of limited vertical range and consequent unquestionable stratigraphic value.† It should, however, at the outset be stated that of the entire flora I have not seen more than three or four forms common to the Pottsville series, and that only one, of doubtful identity, among these occurs below the upper (Sewanee) division of that series. On the other hand, many of the species of wide vertical range are in a general way somewhat characteristic of the Alleghany series.

* About 30 species.

† The occasionally misleading effect of the recorded distribution is especially plain when specimens from widely separated groups, as, for example, the Pottsville series (xii) or the Alleghany series (xiii), and from the Dunkard Creek series (xvi), independently identified, perhaps by different authors or merely from the literature, under the same name, are brought contiguously into a comparison.

Several in this category, however, do not seem to appear below the upper half of this series so that their evidence, though of little weight, tends to corroborate that of the rare Pecopterids in arguing for a stage at some distance above the base of the Lower Productive Coal Measures or Alleghany series.

The synchronologic evidence of the flora will, however, be most succinctly and briefly compassed if we take into consideration the distribution of only those species which, so far as known, have a restricted vertical range. In the following table is given the distribution of the species of limited vertical range as observed * by the writer in the collections from the bituminous coalfields of Illinois, Indiana, Ohio, and Pennsylvania, and from the Northern Anthracite field:

Abridged Distribution in other Basins in the northern United States of the Plants from the Henry County Lower Coals, having, so far as observed, a limited vertical Range in this Country.

Name of species.†	Morris coal or Mazon Creek, Illinois.	Kittanning coals of Indiana or Ohio.	Darlington coal at Cannelton, Pennsylvania.	Anthracite coals of the northern field.	Higher stages.
Eremopteris missouriensis, Lx.	+	.....	.....	.....	.....
Pseudopecopteris obtusiloba, (Brongn.) Lx.	+	.....	.....	.....	.....
Pseudopecopteris squamosa, (Lx.)	+	+	.....	D and E	Kansas.
Mariopteris sphenopteroides, (Lx.) Zeill.	+	.....	.....	.....	.....
Sphenopteris pinnatifida, (Lx.)	+	.....	.....	E (?)	Kansas.
S. mixta, Schimp.	+	(?)	.....	E (?)	Kansas.
S. lacoei, D. W.	.....	.....	+	.....	+ (?)
S. chærophylloides, (Brongn.) Presl.	+	.....	+	D and E	.....
S. cristata, (Brongn.) Presl.	+	.....	+	.....	.....
S. brittsii, Lx.	.....	(?)	.....	.....	.....
Sphenopteris, n. sp.†	+	.....	.....	.....	.....
Sphenopteris, n. sp.†	.....	.....	+	.....	.....
S. subcrenulata, (Lx.)	+	.....	+	.....	.....
Oligocarpia cf. *Gutbiéri*, Goepp.	+	.....	.....	.....	.....
Pecopteris, n. sp.†	+	+	+	.....	.....

* The danger of basing conclusions upon the recorded distribution has been explained in the preceding note. A large portion, perhaps the greater part, of the material on which the geographic record of the Mesocarboniferous species in the United States has been based has been utilized in preparing the present tabulation. The occurrence of species at localities the stratigraphic relations of which are unknown is omitted. This is the case with most of the Rhode Island plants. Reference is made to the horizon only, except in certain instances of exceptionally well elaborated local floras.

† In order to avoid the publication of *nomina nuda* in a communication in the form of an abstract the specific designations of the new species are omitted.

The author is not responsible for the punctuation or capitalization of the plant names, but accepts under protest the system adopted in this publication. He prefers not to use the comma and to retain the capital when the name of a species is derived from that of a person.—EDITOR.

Abridged Distribution in other Basins, etcetera—Continued.

Name of species.	Morris coal or Mazon Creek, Illinois.	Kittanning coals of Indiana or Ohio.	Darlington coal at Cannelton, Pennsylvania.	Anthracite coals of the northern field.	Higher stages.
P. erosa, Gutb.	+	...	+	D, E	Kansas.
P. cf. *arborescens*, (Schloth.) Brongn.	...	(?)	...	E	G +
P. hemiteliöides, Brongn.	...	...	...	...	G +
P. squamosa, Lx.	+	+	+	...	Kans.(?)
P. candolleana, Brongn.	(?)	...	...	E, F	...
P. clintoni, Lx.	(?)	...	...	...	...
P. vestita, Lx.	+	+	+	D (?)	...
Caulopteris, n. sp.*	...	...	+	...	...
Aphlebia hamulosa, (Lx.)	+	...	...	...	...
Aphlebia spinosa, (Lx.)	+	...	...	...	...
Alethopteris ambigua, Lx.	+	...	...	D	...
A. serlii, (Brongn.) Goepp.	+	+	+	C, D, E, F (?)	...
Callipteridium mansfieldi, Lx.	...	...	+	...	...
C. inæquale, Lx.	...	...	+	...	...
C. sullivantii, (Lx.) Weiss.	+	...	+	D, E (?)	G, Kansas.
Neuropteris fasciculata, Lx.	+	...	...	...	...
N. dilatata, (L. and H.) Lx.	...	...	...	D, E	...
Megaphyton goldenbergii, Weiss.	...	...	...	D	...
Asterophyllites longifolius, (Stb.) Brongn.	+	...	(?)	D	...
Calamostachys ovalis, Lx. (?)	...	...	+	...	...
Sphenophyllum emarginatum, Brongn.	+	+	+	D, E	...
S. majus, Bronn	...	...	+	E	Ohio (?)
Volkmannia prælonga, Lx.	...	...	...	D	...
Lepidodendron rimosum, Stb.	+	...	...	E	...
L. clypeatum, Lx.	...	...	(?)	B, C, D (?)	...
Lepidostrobus princeps, Lx.	+	...	...	...	...
Sigillaria camptotænia, Wood.	+	...	+	E	Kansas.
Stigmaria evenii, Lx.	+	...	...	E	...
Tæniophyllum, n. sp.	...	...	+	E	...
Cordaianthus ovatus, Lx.	...	...	+	...	...
C. dichotomus, Lx.	...	...	+	...	...
Rhabdocarpos mansfieldi, Lx.	...	(?)	+	E (?)	
Palæoxyris appendiculata, Lx.	+	...	...	...	...
Forty-eight species	28–30	6-10	22–24	D or E, 19–23	7–10

Approximate Horizon of Henry County Coals as indicated by Fossil Plants.

IN THE BITUMINOUS SERIES.

A review of the foregoing table shows that nearly all the species in the above category have been found either near the Morris coal, in Illinois, or

* Specific name omitted to avoid the publication of *nomina nuda*.

the Darlington and Middle Kittanning coals of Ohio and Pennsylvania Over one-half of the species enumerated have been collected from the horizon first named, and nearly one-half from beds between the latter coals. Almost one-half of the species are present in the *D* or *E* ("Marcy" or "Pittston") coals of the Northern Anthracite field, while nearly one-fifth are found at higher horizons. With the plants of either the Morris-Mazon Creek stage or the Cannelton horizon the affinities of our flora would seem to be almost equally close; but while, as has already been mentioned, the Missouri flora is almost wholly distinct from that of the Pottsville series, and while it is far from confined to the characteristic vegetal associations of the Brookville coal or coals *A* and *B* of the Northern Anthracite field, the large number of species, especially those of wide range, in the Middle Kittanning or higher coals, on the other hand, is highly suggestive of a later age for the Henry County beds than the Clarion or the Morris coals. Unfortunately the plants of the Freeport coal group, as well as those of the entire Lower Barren Measures (XIV), are almost entirely unexploited and unknown. There is little room for doubt, however, that some of these more restricted forms will be found to extend as high at least as the Freeport coals, although the observed disappearance of the earlier forms in passing upward does not warrant the expectation of finding many of the enumerated species at so high a stage. The tendency of the observed range of the species to lead us to conclude that the Henry County flora is later than that of Mazon creek is strongly reinforced by the presence of several Pecopterids,* whose identical or most closely related forms are not yet satisfactorily known in beds lower if so low as the Kittanning coals. In fact, the absence of such later forms in the now fairly well known floras of the lower coals of the Lower Productive Coal Measures (XIII), as well as the close numerical and biological relations of our plants with those of the Kittanning or higher coals, appear to justify the conclusion that the Missouri plants are later than the Brookville and Clarion horizons, though it is not likely that some of the earlier forms extend above the Kittanning group, since they have not yet been met in or above the Middle Kittanning or the Darlington coals. It seems probable, therefore, in view of our present knowledge of the range of the Carboniferous species in this country, that the stage of the lower coals of Henry county is not far from the Lower Kittanning—a conclusion somewhat more definite than, though not really disagreeing with, that reached by Professor Lesquereux.†

IN THE ANTHRACITE SERIES.

In the Northern Anthracite field, in Pennsylvania, the paleobotanical

* For example, *Pecopteris candolleana*, Brongn.; *P. hemitelioides*, Brongn. (?); *Pecopteris* cf. *arborescens*, (Schloth.) Brongn., and a new species not yet known from any other region.

† Coal Flora, vol. iii, 1884, p. 879.

section of the Coal Measures is, thanks to the farseeing and systematic efforts of Mr R. D. Lacoe, of Pittston, Pennsylvania, more completely elaborated than in any other of our Carboniferous basins. A comparison of the range of the Missouri species through the series in the Wyoming valley shows that, while only two of the tabulated species are confined to or are even present in the collections from the coals below the *D* vein, nearly one-half are present in coals *D* or *E*. The occurrence in the flora of the *E* coal of younger types similar to those found in the Missouri material emphasizes the close relation, which is at once apparent from the distribution; but the general character of the flora in hand is far closer to that of the *D* or "Marcy" coal than to any other in the Northern field. On the other hand, many of the earlier types seen among the plants from Missouri or from the *D* coal are wanting in the *E* or "Pittston vein," the roof shales of which are characterized predominantly by forms of later affinities. It is accordingly probable that the stage of the Missouri flora is near that of the Marcy (*D*) coal in the Northern Anthracite field. A study of the distribution of the species nearest related to those in hand leads to essentially the same conclusions.

Relative Age of Henry County Plant Beds.

COMPARISON WITH OTHER FLORAS OF THE UNITED STATES.

The comparison of the flora in hand with other floras and of the vertical distribution of the species, especially in the paleobotanically better known lower two-thirds of the Lower Productive Coal Measures, shows that the lower coals of Henry county, Missouri, were probably deposited later than the Morris coal of Illinois, the Clarion coal of the bituminous regions of Ohio and Pennsylvania, or coal *C* of the Northern Anthracite field, although their deposition can hardly have been so late as the Upper Kittanning coal of the bituminous regions or coal *E* of the Anthracite series, the approximate horizon of the Missouri flora being probably not very far from the Lower Kittanning coal of the bituminous sections and very near to coal *D* of the Northern Anthracite region. Thus the synchronologic evidence of the fossil plants appears to show that the process of the deposition of the Mesocarboniferous terranes was well advanced, so that in the bituminous fields of Illinois, Ohio, and Pennsylvania not only the Pottsville series (XII), ranging from 15 feet to 1,200 feet or more in thickness north of the Potomac river, but also the lower portion of the Lower Productive Coal Measures or Alleghany series (XIII), including probably the Clarion coal, had been laid down on the Eocarboniferous floor before the lower coals in the vicinity of Clinton, Missouri, were sedimented in shallow ponds or marshes fringing the shore of the transgressing Carboniferous sea. The testimony of the plants not only corroborates the observations of the state geologists * as to the probable concealment in that region of the earlier beds of the Coal Measures beneath the overlapping margins of the later terranes, but it also approximately fixes for the Henry County district the time at which the eroded Mississippian shore passed beneath the encroaching sea. The unconformity between the Jordan coal and the locally essentially subjacent Eocarboniferous terranes covers a period including the sedimentation of Mesocarboniferous terranes attaining a maximum thickness of over 1,200 feet in Pennsylvania and exceeding 2,500 feet in southern West Virginia and Alabama.

VERTICAL RANGE OF THE MISSOURI SPECIES IN THE BRITISH COALFIELDS.

One of the most interesting facts which appear to every student of Paleozoic plants is the remarkable degree of identity between the plant species of the Carboniferous in this continent and those of the old world. The identities and obviously close intercontinental relationships are not less striking than are the similarities in the elemental composition of the flora of each successive stage and the essential general regularity in the order of the sequence of the various floral associations. In the two following tables showing, in part only, the foreign distribution of the Missouri species the first of these conditions very imperfectly appears, but it is not within the limits of the present paper to further illustrate or amplify either subject.

The following table indicates the vertical range in the principal divisions of the Coal Measures of Great Britain of (1) the species common to Henry county and the British coalfields, and the range in the latter of (2) a number of old world species whose relationships to ours are sufficiently intimate to lend an inferential significance to their stratigraphic occurrence.†

It will at once be seen in a glance at the accompanying table that the greater portion of the identical species are found in the Middle Coal Measures and the Upper Coal Measures of Great Britain. Only about one-half as many are present in the Lower Coal Measures as in either of the divisions just named, and these species are generally plants of wide vertical range. Judged, therefore, by the numerical proportions, it would seem that the Henry County flora is so equally bound to both the Upper and the Middle Coal Measures as to suggest an intermediate posi-

*See Winslow: Bull Geol. Soc. Am., vol. 3, 1891, pp. 109–121; Preliminary Report on Coal of Missouri, 1891, p. 19; also Keyes: Am. Geologist, vol. xii, 1893, p. 100.

† For the British distribution of the species I am indebted to a valuable and critically painstaking memoir by Mr Robert Kidston, "On the Various Divisions of the British Carboniferous Rocks as determined by their Fossil Flora." Proc. Royal Phys. Soc. of Edinburg, vol. xii, 1894, pp. 183–257.

Distribution of the identical or closely related Species in the Divisions of the Coal Measures of Great Britain.

Name of species. (Related species in parentheses.)	Upper Carboniferous.				
	Millstone grit.	Lower Coal Measures.	Middle Coal Measures.	Transition series.	Upper Coal Measures.
Excipulites callipteridis, (Schimp.) Kidst.					+
Pseudopecopteris obtusiloba, (Brongn.) Lx.		+	+		
P. squamosa, (Lx.)				+	+
Mariopteris cf. nervosa. (*M. nervosa* (Brongn.) Zeill.)	+	+	+		
M. sphenopteroides, (Lx.) Zeill. (*M. acuta*, (Brongn.) Zeill.)		+	+		
Mariopteris, sp. nov.* (*Sphenopteris jacquoti*, (Zeill.) Kidst.)			+		
Sphenopteris mixta, Schimp.			+		
S. lacoei, D. W. (*S. rotundifolia*, Andrä)			+		
Sphenopteris, sp. nov.* (*Hymenotheca dathei*, Pot.)			+		
Sphenopteris, sp. nov.* (*S. woodwardii*, Kidst.)					+
S. pinnatifida, (Lx.) (*S. quadridactylites*, Gutb.)			+		
S. cristata, (Brongn.) Presl			+		
Sphenopteris subcrenulata, (Lx.) (*Pecopteris crenulata, Brongn.*)					+
Oligocarpia, sp. nov.* (*O. brongniartii*, Stur)			+		
Pecopteris, sp. nov.* (*Sphenopteris sternbergii*, (Ett.) Weiss)		+	+		
Pecopteris erosa, Gutb					+
P. dentata, Brongn.			+		+
P. cf. arborescens. (*P. arborescens*, (Schloth.) Brongn.)					+
P. hemitelioides, Brongn. (?) (*P. arborescens* (Schloth.) Brongn., var. *cyathea*, (Brongn.) Kidst.)					+
Pecopteris, sp. nov.* (*P. oreopteridia*, (Schloth.) Brongn.)					+
P. candolleana, Brongn.					+
P. squamosa, Lx. (*P. lamuriana*, Hr.)					+
P. vestita, Lx. (*P. villosa*, Brongn.)					+(?)
Aphlebia spinosa, (Lx.)					+

*Specific name omitted to avoid the publication of *nomina nuda*.

Distribution of the identical or closely related Species, etcetera—Continued.

Name of species. (Related species in parentheses.)	Upper Carboniferous. Millstone grit.	Lower Coal Measures.	Middle Coal Measures.	Transition series.	Upper Coal Measures.
A. crispa, (Gutb.) Presl					+
A. filiciformis, (Gutb.) Sterz					+
Aphlebia, sp. nov.*					
(*A. goldenbergii*, (Weiss)					+
Alethopteris ambigua, Lx.					
(*A. aquilina*, (Schloth.) Goepp.)			+		+
A. serlii (Brongn.) Goepp			+	+	+
Callipteridium mansfieldi, Lx.					
(*Alethopteris grandini*, (Brongn.) Goepp.)					+
C. inæquale, Lx.					
(*A. davreuxii*, (Brongn.) Goepp. ?)			+		+
Odontopteris bradleyi, Lx.					
(*O. lindleyana*, Stb.)				+	+
Neuropteris rarinervis, Bunb			+	+	+
N. missouriensis, Lx.					
(*N. flexuosa*, Stb.)				+	+
N. fasciculata, Lx.					
(*N. macrophylla*, Brongn. ?)				+	+
N. scheuchzeri, Hoffm			+	+	+
N. dilatata, (L. and H.) Lx			+		
Dictyopteris, sp. nov.*					
(*D. münsteri*, (Eichw.) Brongn.)			+		+
Calamites ramosus, Artis		+	+		+
C. suckowii, Brongn	+	+	+		+
C. cistii, Brongn		+	+	+	+
Asterophyllites equisetiformis, (Schloth.) Brongn		+	+	+	+
A. longifolius, (Stb.) Brongn		+	+		
Calamostachys ovalis, Lx. (?)					
(*Palæostachya pedunculata*, Will.)		+	+		
Annularia stellata, (Schloth.) Wood				+	+
A. sphenophylloides, (Zenk.) Gutb			+	+	+
A. ramosa, Weiss.					
(*A. radiata*, (Brongn.) Stb.)		+	+		
Cyclocladia, sp. nov.					
(*Macrostachya infundibuliformis*, (Bronn) Schimp.)					+
Radicites capillacea, (L. and H.) Pot		+	+		+
Sphenophyllum cuneifolium, (Stb.) Zeill		+	+	+	
S. emarginatum, Brongn				+	+
S. majus, Bronn		+	+		+
Sphenophyllum, sp. nov.*					
(*S. oblongifolium*, (Germ.) Ung.)			+(?)		

* Specific name omitted to avoid the publication of *nomina nuda*.

Distribution of the identical or closely related Species, etcetera—Continued.

Name of species. (Related species in parentheses.)	Upper Carboniferous.				
	Millstone grit.	Lower Coal Measures.	Middle Coal Measures.	Transition series.	Upper Coal Measures.
Lepidodendron brittsii, Lx.					
(*L. wortheni*, Lx.)	.....	.....	+	+	+
L. lanceolatum, Lx.	.....	.....	.....	.....	+
L. rimosum, Stb.	.....	.....	+	.....	.....
L. scutatum, Lx.					
(*L. ophiurus*, Brongn.)	.....	+	+	.....	.....
Lepidostrobus princeps, Lx.					
(*L. geinitzii*, Schimp.)	.....	+	+	.....	.....
Lepidophyllum, sp nov.*					
(*L. triangulare*, Zeill.)	.....	.....	+	.....	.....
Sigillaria camptotænia, Wood	.....	+	+	+	+
S. tessellata, (Steinh.) Brongn.	+	+	+	+	+
S. ovata, Sauv.	.....	.....	+	.....	.....
Stigmaria verrucosa (Martin) Mill	+	+	+	+	+
S. evenii, Lx.	.....	.....	.....	+	.....
Cordaites communis, Lx.					
(*C. borassifolius*, (Stb.) Ung.)	.....	+	+	.....	+
Cordaianthus ovatus, Lx.					
(*C. volkmanni*, (Ett.) Zeill.)	.....	.....	+	.....	.....
Rhabdocarpos multistriatus (Presl.) Lx	.....	.....	.....	.....	+
Palæoxyris appendiculata, Lx.					
(*P. carbonaria*, Schimp.)	.....	.....	+	.....	.....
Summary.... { Identical species..... 34	1	12	22	14	25
Summary.... { Related species...... 34	3	8	21	4	18

tion. Through its Sphenopteroid elements it is intimately connected with the Middle Coal Measures; but in England as well as in America the progression from the lower to the higher terranes of the earlier Coal Measures proper is in general marked by the appearance and elaboration of the Pecopteroid forms simultaneously with the disappearance of the early Mariopteroid and Pseudopecopteroid forms of the basal Coal Measures, or such as have survived from the "Millstone Grit" or the Pottsville series. It is largely to the proportion of identical or related species* of *Pecopteris* and the intimately connected *Aphlebiæ* that the ap-

* Although but slight weight should be attached to the evidence afforded by the related species, their testimony in this as well as in the following table seems practically to corroborate that of the identical species.

proximate equality of the percentages in this table is due; but the Upper Coal Measures of Great Britain contain many higher forms, such as *Pecopteris polymorpha*, Brongn., *P. miltoni*, Artis, and *P. pteroides*, Brongn., besides the *P. arborescens*, Brongn., and other higher forms, which are not present in our flora, while the general character of the plants of that division is of a rather higher order. In brief, considering this important circumstance on the one hand as well as the relations evidently later than the Middle Coal Measures on the other hand, we may, it would seem, safely conclude that the lower coals in the vicinity of Clinton are certainly not older than the Middle Coal Measures of Great Britain, but most probably younger, or that they are presumably as late as the Transition series,* whose flora, though as yet but little exploited, shows relatively the closest affinities. It is quite possible, however, that the deposition of our flora was even so late as the sedimentation of the basal portion of the Upper Coal Measures of the British coalfields.

STRATIGRAPHIC RANGE IN THE FRANCO-BELGIAN FIELD.

To indicate in part the relation of our flora to those of Continental Europe we may take into comparison, as typically illustrating the succession of plant life in Europe during this portion of Carboniferous time, the series developed in the Valenciennes basin of the Franco-Belgian coalfield, the floras of which have been elaborated with masterly thoroughness and skill by René Zeiller.† The distribution of the identical Henry County plants as well as of the related species ‡ in the three paleontological zones, into which M. Zeiller finds the Valenciennes series (*Houiller Moyen*) to be divided, is shown on the accompanying table.

The limit of space precludes in this place any remark on either the paleontological characters of the three zones or the surprising degree of similarity between the Missouri flora and that of the upper zone of the Valenciennes series. A short inspection of the tabular columns shows that while only a relatively small percentage of our species is present in the lower zone, over one-half are found in the Middle (Anzin-Meurchin) zone, but the conspicuous feature is the occurrence of 24 or 25 of the 26 identical species in the Upper (Bully-Grenay) zone. The evidence afforded by the distribution of the species needs only to be supplemented by a review of Zeiller's profuse and admirably executed figures of the species in the Upper zone to carry the conviction that in

* The New Rock and the Vobster series of the Bristol and Somerset coalfield and the "Lower Pennant" of the South Wales coalfield.

† Études des gites minéraux de la France. Bassin houiller de Valenciennes. Description de la Flora Fossile, par R. Zeiller. Ministère d. travaux publics, etc., Paris, text, 1888, pp. 1–731, quarto; 1886, atlas, pls. i–xciv, quarto.

‡ The related species (parenthesized), the distribution of which is given, is written subjacent to the respective American species.

Distribution in the Valenciennes Basin (Houiller Moyen) of Species identical with or closely related (in parentheses) to those from Missouri.

Name of species.*	Lower zone.	Middle zone.	Upper zone.
Eremopteris missouriensis, Lx.			
(*Diplothmema furcatum*, (Brongn.) Stur?)	......	R	R
Pseudopecopteris obtusiloba, (Brongn.) Lx	+	+	C
P. squamosa, (Lx.)	......	+	C
Mariopteris cf. nervosa.			
(*M. muricata*, (Brongn.) Zeill.)	R	R	R
M. sphenopteroides, (Lx.) Zeill	......	......	+
Mariopteris, sp. nov.*			
(*Diplothmema jacquoti*, Zeill.)	......	......	R
Sphenopteris mixta, Schimp	......	.....	+
S. pinnatifida, (Lx.)			
(*S. quadridactylites*, Gutb.)	......	R	R
S. chærophylloides, (Brongn.) Presl	......	......	+
S. cristata, (Brongn.) Presl.			
(*S. douvillei*, Zeill.)	......	......	R
Sphenopteris, sp. nov.*			
(*Diplothmema zeilleri*, Stur)	....	......	R
Sphenopteris, sp. nov.*			
(*S. potieri*, Zeill.)	......	......	R
S. ophioglossoides, (Lx.)			
(*S. crepini*, Zeill.)	......	......	R
S. subcrenulata, (Lx.)			
(*Pecopteris crenulata*, Brongn.)	......	......	R
Oligocarpia, sp. nov.*			
(*O. brongniartii*, Stur)	......	R	R
Pecopteris, sp. nov.*			
(*Sphenopteris sternbergii*, (Ett.) Weiss)	......	R	R
P. dentata, Brongn. (non Will.)	+	+	+
Pecopteris, sp. nov.*			
(*P. abbreviata*, Brongn. ?)	......	R	R
P. vestita, Lx.			
(*P. volkmanni*, Sauv. ?)	R	R	.....
P. clintoni, Lx.			
(*P. integra*, (Andrä) Schimp.)	......	......	R
Aphlebia crispa, (Gutb.) Presl	......	+	+
Alethopteris serlii, (Brongn.) Goepp	.....	+	C
Callipteridium cf. mansfieldi, Lx.			
(*Alethopteris grandini*, (Brongn.) Goepp.)	......	......	R
Neuropteris rarinervis, Bunb	......	+	C
N. missouriensis, Lx.			
(*N. flexuosa*, Stb.)	R	R	R
N. scheuchzeri, Hoffm.	......	+	+

* The full names of new species are omitted to avoid the publication of *nomina nuda*.

The foreign species related to a corresponding one from Missouri is placed in parenthesis subjacent to the latter.

The names used are not in all cases those given preference in M. Zeiller's memoir.

The significance of the signs given in the table are as follows: + = present; R = distribution of related species; C = common.

Distribution in the Valenciennes Basin (Houiller Moyen), etcetera—Continued.

Name of species.	Lower zone.	Middle zone.	Upper zone.
Dictyopteris, sp. nov.*			
(*D. münsteri*, (Eichw.) Brongn.)	......	......	R
Calamites ramosus, Artis	+	+	+
C. suckowii, Brongn.	+	+	C
C. cistii, Brongn.	+	+	+
Asterophyllites equisetiformis, (Schloth.) Brongn	......	+	C
A. longifolius, (Stb.) Brongn.	......	+	(?)
Calamostachys ovalis, Lx.?			
(*Palæostachya pedunculata*, Will.)	......	R	......
Annularia sphenophylloides, (Zenk.) Gutb.	......	......	C
A. stellata, (Schloth.) Wood.	......	......	+
Radicites capillacea, (L. and H.) Pot.			
(*Pinnularia columnaris*, (Artis) Zeill.)	......	......	R
Sphenophyllum cuneifolium, (Stb.) Zeill.	+	+	+
S. emarginatum, Brongn.	......	+	C
S. majus, Bronn.	......	......	+
Lepidodendron brittsii, Lx.			
(*L. wortheni*, Lx.)	......	R	......
L. rimosum, Stb	......	+	......
L. lanceolatum, Lx.			
(*L. lycopodioides*, Stb.?)	......	R	R
L. scutatum, Lx.			
(*L. ophiurus*, Brongn.)	......	R	......
Lepidostrobus princeps, Lx.			
(*L. geinitzii*, Schimp.)	......	R	......
Lepidophyllum, sp. nov.*			
(*L. triangulare*, Zeill.)	......	R	R
Sigillaria camptotænia, Wood	......	+	C
S. tessellata, (Steinh.) Brongn	......	+	C
S. ovata, Sauv.	......	+	+
Stigmaria verrucosa, (Martin) S. A. Mill	+	+	+
S. evenii, Lx.	......	......	+
Cordaites communis, Lx.			
(*C. borassifolius*, (Stb.) Ung.?)	......	R	R
Cordaianthus ovatus, Lx.			
(*C. volkmanni*, (Ett.) Zeill.?)	......	......	R
Total ... { Identical species ... 26	7	19	25
Total ... { Related species ... 26	3	15	21

the upper terranes of the Valenciennes series we find sediments very nearly contemporaneous with the lower coals of Henry county. In fact, if we assume a generally uniform distribution of the plants, there can be little doubt that the floras are nearly synchronous. It is, however, not wholly improbable that the Missouri plant beds may be slightly younger, since our Pecopteroid forms include species of a Stephanian character,

* The full names of new species are omitted to avoid publication of *nomina nuda*.

tending to lead from the Valenciennes series (Westphalian) to the Stephanian.* The presence of these types in the Henry County beds, as well as the comparative absence from them of the species more characteristic of the Middle zone of the Valenciennes basin, indicates for our flora a greater and more significant affinity with that in the terranes succeeding, in time, the zone of Bully-Grenay than with that of the beds below this zone. Hence, taking all things into consideration, we will perhaps be warranted in concluding that the Missouri flora represents a stage close to, but below, the upper limit of the Westphalian.

SUMMARY OF CONCLUSIONS RESPECTING THE STAGE OF THE MISSOURI FLORA IN THE OLD WORLD BASINS.

In passing, it should be noted that the Transition series in Britain and the zone of Bully-Grenay, to both of which our flora seems to refer us,† have been quite independently correlated with each other by Zeiller and Kidston. So also the tendency of the Missouri flora toward that succeeding the upper zone of the Valenciennes series appears to harmonize with the reference made by Zeiller ‡ of the Mazon Creek flora to the zone of Bully-Grenay.

The study of the distribution of our flora in other European basins indicates an approximately contemporaneous stage in the Geislautern beds near the top of the Saarbrück series of the Rhenish coal regions, in the upper part of the Schatzlar series, and in the Radnitz series in central Bohemia.

General Considerations as to the early Carboniferous Flora.

The study of the geographic distribution of the Mesocarboniferous floras throughout the northern hemisphere shows (1) so striking a general parallelism in the succession of the floras, (2) so high a degree of uniformity in the elemental composition and relations of the floras of the respective stages in the different basins, and (3) so large a proportion of the genera, and species even, that are identical and in similar general sequence, both with respect to their associates and with regard to their relative period of existence, not merely in the basins of the same continent, but between Europe or Asia and north America,§ as not only to

* Several of our species are more nearly related to forms in the Commentry flora (Stephanian) than those forms from the Franco-Belgian field tabulated above.

† As remarked above, it may be slightly later than either.

‡ Op. cit., p. 195.

§ Forty-one of the 44 genera present in the Henry County flora are also found in the European coalfields, while the proportion of identical species may, even with the refinement of differentiation that now prevails in Paleozoic paleobotany, ultimately be found to comprise far more than one-half of the entire flora.

apparently indicate an almost incredible uniformity in climate over the northern hemisphere during that period, but to necessitate also the assumption of such intercontinental relations and conditions as to furnish wonderful facilities for the exceedingly rapid, almost simultaneous, distribution of the genera and species. The writer is disposed to believe that the conditions favorable to plant distribution and comparatively uniform dispersion over the greater part of the Arctic hemisphere during the period extending from the later Culm to near the middle of the Mesocarboniferous have never been equaled since. That there was plant migration cannot for a moment be questioned; yet, viewed from a broad standpoint, the evidence of the horizontal distribution, of the vertical range, of characteristic associations (such as are to be found in the Valenciennes and Missouri coalfields) in the different zones, and of the comparatively regular succession of the floras bespeaks for the terrestrial plant species of that period such climatic conditions and such facilities for rapid intermigration* as to justify us in regarding the remarkably similar association of identical genera and identical or closely allied species which characterizes a group, zone, or, not infrequently, stage of the various basins of that epoch as essentially or approximately contemporaneous in all those basins.

It has been the custom in this country to regard the well known flora of Mazon creek as representative of the plant life in existence in the earliest Lower Coal Measures time, there being but little difference between it and the plants of the bituminous Brookville and Clarion coals, the lower of which is probably fully as old as the "Buck Mountain vein," the conventional baseline of the Coal Measures in the Southern and Middle Anthracite fields. On the other hand, certain European paleobotanists have suggested that the flora of Mazon creek really represents a stage much higher than the lowest terranes above the "Millstone Grit."

An examination of the distribution of the species will show, if we admit the synchronologic value of the floras, that the plants of the Upper Kittanning coal of the bituminous series or of the *E* vein of the Northern Anthracite field, fall within and are probably contemporaneous with some portion of the Geislautern beds, or the upper beds of the Westphalian (*Saarbrücker Schichten*), while the flora of the *G* vein of the same anthracite field is clearly referable to the Stephanian (*Ottweiler Schichten*), as appears also to be the imperfectly known flora of the Pittsburg coal.†

In those regions of Missouri, Illinois, Indiana, Ohio, and western Pennsylvania in which the plants from the lowest coals have been studied,

* Possibly over a minimum distance under the favoring advantage of a polychthanous development of certain types.

† The flora of the Freeport coals is so nearly unknown that its relations to those of other stages or the Anthracite series is still quite uncertain.

there is a strongly marked contrast between the flora of those coals and the species found in the Pottsville series or "Millstone Grit," which lies, in most cases, close beneath them, there being in fact very few species in common. The plants of the upper portion of the Pottsville series agree in the main with the flora of the Millstone Grit of Europe. The Lower Coal Measures of Great Britain and the zone of Vicoigne in the Franco-Belgian basin, with their intermingling of Millstone Grit or Culm species with the earliest of the Coal Measures types, appear, so far as we know at present, to be unrepresented by any coal-bearing interval in the bituminous regions mentioned above. It seems more probable, however, that this interval is in some cases concentrated in the deposition of the highly variable upper benches of the Pottsville series in the northeastern states, rather than that it is represented in these regions by a break or that we have here a case of homotaxy without contemporaneity in the floras. It is proper to state in this connection that in the greatly expanded sections of the Lower Coal Measures in the Upper Kanawha region of West Virginia, which is in the same great Appalachian basin and which was throughout Mesocarboniferous time united with the northern plant-bearing areas by continuous shorelines, the characteristic forms of the lowest coals of the Lower Productive Coal Measures of the states north of the Ohio and Potomac rivers are not met until we arrive at a point several hundred feet above the Pottsville series as hitherto limited. The floras of the Kanawha series, extensive collections from which are now in the writer's hands for examination, will be found to show a lower zone of mingled types corresponding very closely to the Lower Coal Measures of Great Britian or the lower zone of the Franco-Belgian basin.

CHARACTERISTIC SCENE IN THE DAEMONELIX BEDS

Showing forms of Daemonelix partly worked out; also showing fibers penetrating the sand-rock in various directions.

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NATURE, STRUCTURE, AND PHYLOGENY OF DAEMONELIX

BY ERWIN HINCKLEY BARBOUR

(*Read before the Society December 31, 1896*)

CONTENTS

INTRODUCTION.

Since the first expedition in 1891 to the lofty Pine Ridge tablelands of Sioux county, Nebraska, which led to the discovery of the Daemonelix beds, annual expeditions to the same fields have become possible through the liberal patronage of the Honorable Charles H. Morrill, of Lincoln. To his generosity must be accredited the progress made in the study of these beds which we are now enabled to report.

Below Pine Ridge lie the well known Hat Creek badlands in the Miocene formation. The topography here is characteristic of a clay region subject to excessive erosion. It is typical badland.

Overlying it and rising above it by nearly vertical walls, 1,000 to 1,200 feet in height, is the Pine Ridge tablelands. Here the sands of the Loup Fork Tertiary, in which Daemonelix is found, are cut into bluffs, buttes, blowouts, and precipitous canyons.

Some four or five hundred square miles characterized by such topography have been explored, even into Wyoming, and Daemonelix is found to be an ever present and striking feature. As nearly as the author can learn, the rangers and ranchmen have known of these stone "screws," "twisters," or "Devil's corkscrews" for 15 or 20 years, yet they escaped public notice until the expeditions sent thither by the University of Nebraska reported them, for the first time, in Science of February 19, 1892.

The Devil's corkscrews, found in the topmost beds, from their very size and symmetry force themselves into prominence at once. However, upon passing from the lower beds to the higher, as can easily be done by ascending a canyon, forms varying from simplicity and uniformity to those of ever-increasing diversity and complexity are found, the climax being reached in the topmost beds. This looks like phylogeny. Though hesitating since the first expedition to say so, subsequent exploration and study have so far confirmed the first observations and impressions that the author feels warranted in proposing this as so many possible steps in the phylogenetic history of a new fossil. If so, this is a fundamental discovery in the study of Daemonelix, and the beds thereby may readily be divided into lower, middle, and upper. Be this as it may, the fact of increasing diversity and complexity from bottom to top remains.

Mode of Occurrence.

DAEMONELIX FIBERS.

The simplest form of the Daemonelix series is a hollow tubule or fiber, which is found throughout the Daemonelix beds, from bottom to top, sometimes penetrating the sand-rock like rootlets, or growing in thin mats along fissures, or gathered into great shapeless masses (see plate 32, figures 1, 2, 3, 4).

Often delicate tracings of these forms are found on the fossils of the region. It may be but a simple fiber growing close upon a bone, or this by branching may have dimensions in two directions, and thus partly veil or cover the fossil with its meshes. Again, it may have growth in three dimensions, and thus completely enclose the submerged form on which the simple plant began. Our collections have innumerable examples of each and all of these conditions.

It is a matter of frequent occurrence to find fossil bones distinctly and unmistakably etched by the growing fibers of those days.

Let it be distinctly stated here that it is this self-same fiber and none other which goes to make up each one of the varying forms of the whole Daemonelix series, and the author's belief is that it is according to the arrangement or aggregation of these fibers into this shape or that, that

Daemonelix Fibers

Figure 1.—Daemonelix tubule found grown to rhinoceros bone.
Figure 2.—Daemonelix fiber found in the sand-rock.
Figure 3.—Jaw bone (25 cm. long) partly grown over with Daemonelix fibers.
Figure 4.—Toe bone etched by Daemonelix fibers.

Daemonelix Cakes

Figures 5, 6, and 7.—Top, side, and bottom views of Daemonelix cake, showing mat of tubules (natural size).
Figure 8.—Section of cake showing periphery of tubules.

DAEMONELIX FIBERS AND CAKES

the multifarious forms result. The one is but a simple fiber, the others but aggregations or colonies of them, so far as the eye or the microscope itself, for that matter, can see. There exists neither superficial nor structural differences of any kind, so far as can be learned, between the primitive tubule and the complex forms. Pick such a fiber from the sand-rock, or from a fossil bone, or from any of the Daemonelix group, even from that splendid spiral aggregation, the Devil's corkscrew itself, and all are precisely alike. Cut sections of them for the microscope and each and every one shows exactly the same cellular, non-vascular, parenchymatous tissue. The fiber is the elemental or fundamental part of Daemonelix.

DAEMONELIX CAKES.

On ascending the canyon toward Eagle Crag, where the chance for observation is especially favorable, one comes to the forms next in simplicity, which for lack of a better name the students of our party dubbed "Daemonelix cakes." They are, in fact, not wholly unlike camp griddle cakes in point of shape, size, and thickness as well as in the manner in which they, batter-like, threw out occasional pseudopodia-like lobes. The cakes occur very abundantly throughout a vertical range of some 6 to 8 meters, at a level of from 50 to 60 meters below the regular Daemonelix beds, and as they stand, weathered out, on the sides of the canyon they look like great beds of bracket fungus. Neither below this horizon nor above have they been found. Though often solitary, they are not infrequently in groups of twos and threes, and occasionally in large clusters. In the last case it is interesting to note that they rise one above another in steps or terraces, the plane of each being coincident with the bedding plane (see plate 32, figures 5, 6, 7, 8).

Though commonly circular in form, many are irregularly lobed, as if the plant had thrown out filamentous aggregations in various directions.

As to dimensions, they are seldom more than 5 to 10 centimeters across, and in thickness vary from ½ to 2 centimeters.

Possibly as sedimentation went on the original cake was choked and covered with sand, save a vigorous offshoot or so which grew upward and spread out as before, but on a higher level, and so for each succeeding member of the whole cluster. Be this as it may, it is evident at a glance that there is organic connection between the individual components of such a cluster.

The bottoms of the so-called cakes lie in horizontal planes, as if in conformity to the bed of the Pliocene lake on which they grew. May we not conceive of this filamentous alga, or of these rootlets, or whatever they are, as growing in a closely tangled mass or colony, flat on the sandbars of this lake, to be covered with sand as deposition progressed?

These are not water-worn fragments of the Devil's corkscrew, but are forms distinct and characteristic and confined to a definite horizon, as shown by hundreds of them found in position.

Superficially, the structure of Daemonelix cakes, like that of each and every form of this puzzling series, consists of a tangle of Daemonelix fibers. A fractured surface shows a periphery of interlacing tubules encircling a core of sand, traversed here and there by stray fibers.

Microscopically, there is precisely the same tissue found at the outset in the primitive fiber. We have cut sections from every part of many individual Daemonelix cakes, with the unvarying result that the cellular structure, though perfectly preserved in some sections and imperfectly in others, is lacking in none.

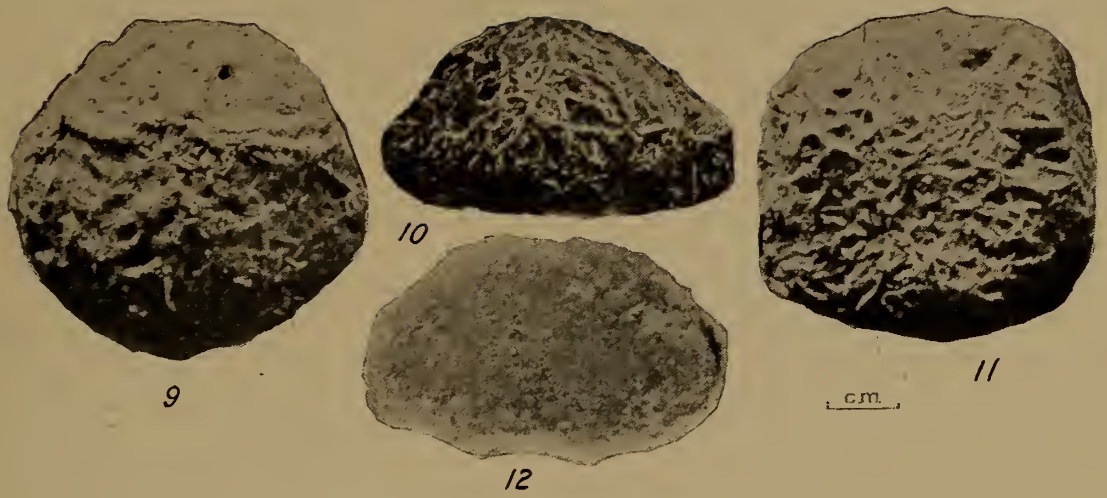
DAEMONELIX BALLS.

Ascending the canyon, one comes next to a form closely allied to the foregoing in every essential. These the students named Daemonelix "balls," because of a real or fancied resemblance to the old-fashioned New England codfish ball. As to mode of occurrence, they were found in great numbers, weathered out and tumbled together at the base of the canyon and also *in situ*, being confined to a vertical range of eight meters, directly overlying the Daemonelix cakes (see plate 33, figures 9, 10, 11, 12). Though so like the cakes in every essential, the balls differ superficially in that they are smaller in circumference, more regular and uniform in size, of greater complexity, and that they are solitary. Superficially they are like the Daemonelix cakes; microscopically they are identical, and words need not be multiplied.

DAEMONELIX CIGARS OR FINGERS.

Continuing the ascent of the canyon toward Eagle Crag, one comes next upon forms much more advanced and complex, called by the students Daemonelix "cigars" or "fingers." Immense numbers of the tip ends of these, weathered out and lying at our feet, did suggest a resemblance which, though remote, justified the name. As to range, the cigars, unlike the preceding forms, are not restricted to a given horizon, but are found in increasing numbers from their first appearance to the middle of the regular Daemonelix beds, and in diminishing numbers thence to the topmost.

In outward appearance they have acquired a pronounced vertical habit and a noticeable tendency to a spiral form. When found in position they are about the size of an ordinary cane. A few exceed a meter in height. At times a specimen is loosely branched, though ordinarily



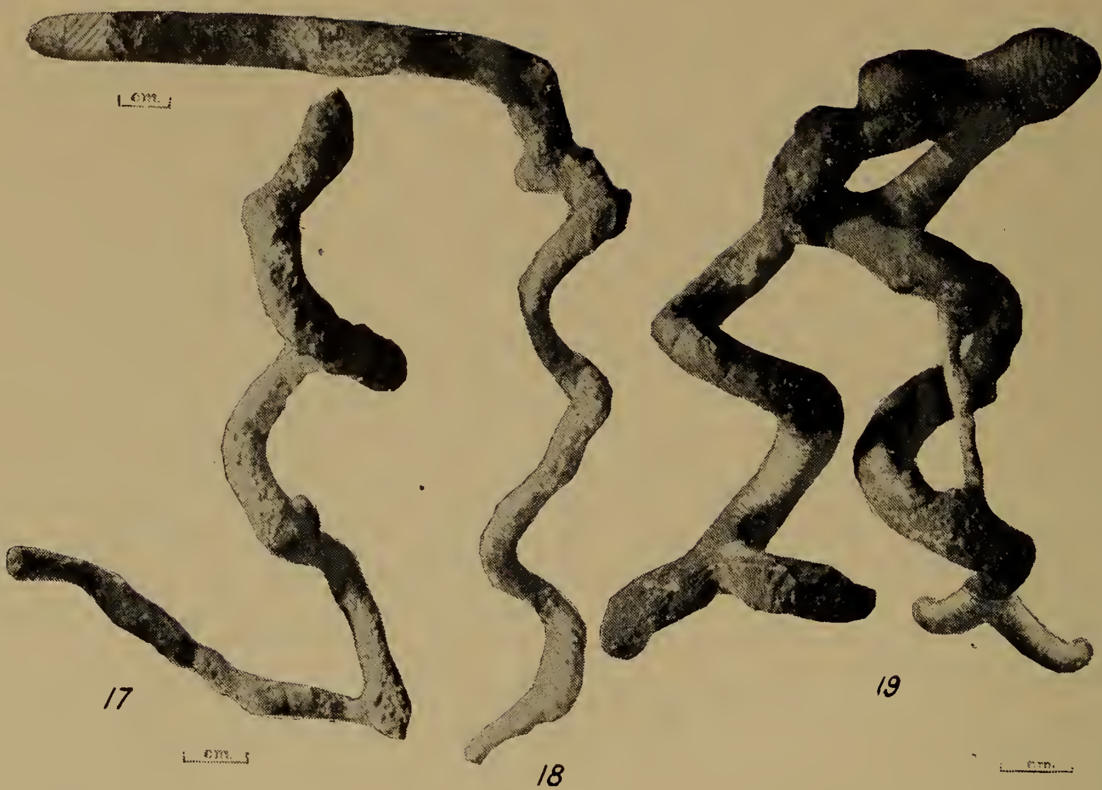
DAEMONELIX BALLS

Figures 9, 10, and 11.—Top, side, and bottom views of Daemonelix ball, showing superficial mat of tubules.
Figure 12.—Cross-section of same, showing periphery of tubules.

DAEMONELIX CIGARS OR FINGERS

Figures 13, 14, and 15.—Tip ends of Daemonelix cigars, showing characteristic forms.
Figure 16.—Longitudinal section and cross-section of same, showing periphery of tubules (all nearly natural size).

DAEMONELIX BALLS AND CIGARS OR FINGERS



DAEMONELIX IRREGULAR

Figures 17 and 18.—Nearly complete specimens.
Figure 19.—A complete specimen. These specimens were found in the middle beds.

DAEMONELIX REGULAR

Figure 20.—Free spiral (from Eagle crag).
Figure 21.—Free spiral ending in enlargement (in National Museum).
Figure 22.—Free spiral ending in three spherical enlargements and one small process.
Figure 23.—Free spiral ending in transverse trunk or "rhizome."
Figure 24.—Spiral and axis and transverse trunk.
Figure 25.—Free spiral with two transverse trunks.
Figure 26.—Massive free spiral with three transverse trunks.
Figure 27.—Example of twin screws.
Figure 28.—Complex Daemonelix, showing two spirals, one free, the other coiled around an axis, together with numerous spurs or processes of various forms and sizes, the upper whorl being surrounded by a crown of such spurs.

DAEMONELIX IRREGULAR AND REGULAR

it is but a frail vertical form, somewhat spiral, without branch or division (see plate 33, figures 13, 14, 15, 16).

The fact that the branches as well as the upper and lower extremities terminate in blunt, rounded ends, completely grown over and sealed, makes it difficult to determine whether the cigars grew upward or downward, but is conclusive evidence that these frail forms, with exit and entrance capped over and sealed, could not have been burrows. Though strikingly similar, three or four distinct forms are already recognized.

Superficially they are characterized by the same fibrous mat surrounding the same core of sand as in the case of the two preceding forms. At the tip ends the structure is densest and best preserved.

Structurally there is not visible to the microscope a variation from the types already described.

DAEMONELIX IRREGULAR.

Continuing the ascent of the canyon, one comes next to the middle Daemonelix beds, characterized by slender, branching, vertical, spiral forms, which the party called Daemonelix " irregular " in contradistinction to the Daemonelix regular, or Devil's corkscrews, found in the upper beds (see plate 34, figures 17, 18, 19).

As to mode of occurrence, it may be stated, they are found through a vertical range of six to eight meters in the middle beds, never occurring below this level, although above it they are occasionally met with well up to the topmost beds. They are always vertical or nearly so. Like the cigars, these irregular twisters end in blunt rounded terminations, sealed or capped with plant fibers, leaving neither exit nor entrance for the supposed occupants of the so-called burrows. One complete specimen and many nearly so have been found, as shown in figures 17, 18, 19. There is extreme perplexity and embarrassment in accounting for the irregular form shown in figure 19, with its peculiar top and its pair of spirals branching dichotomously below. No explanation is adequate. It is one of those singular cases which cannot be, yet is. The inference from the branching is that the seaweeds or rootlets, or whatever organism it is, grew downward in the sand, not upward in the water. Assertions cannot be made. This much, however, is certain, that the irregular twisters, like their supposed precursors, the cakes, balls, and cigars, are unmistakably organic, consisting of a superficies of exactly the same simple fibers, surrounding in a similar manner a core of sand, penetrated by scattered tubules. Neither the eye nor the glass can detect any structural difference whatever between these and all preceding as well as succeeding forms. The gross structure and the minute are identical. In size and shape and in these alone do they differ. What describes one virtually describes all.

DAEMONELIX REGULAR.

The explorer has reached now the beds of the Devil's corkscrews, those magnificent spirals which were first found and described. Here a sheer wall exposes to full view a section fully 40 to 45 meters from bottom to top, with innumerable twisters at every level. It may not be amiss to note in this connection that from a neighboring eminence the eye can see in one view all that has been mentioned in ascending the canyon, thus converting it into one continuous vertical section from 60 to 70 meters, or thereabouts, from bottom to top. The first general fact respecting the twisters which impresses the observer is that of the increasing size, diversity, and complexity of the Devil's corkscrews from their first occurrence below to their culmination above (see plate 34, figures 20, 21, 22, 23, 24, 25, 26, 27, 28).

Those at the bottom, constructed as they are upon smaller and more uniform lines, stand in bold contrast to those large and diversified forms, subject to sudden and startling modifications and variations, found at the top.

However similar or diverse, there is no exception to the rule that they are invariably upright, a fact which adds very apparent complexity to this vexed question.

There are two forms of the Devil's corkscrew, one with an axis, now known to be rare, and one without. Both screws twist to the right or left indiscriminately. Both are mathematical spirals, tapering from top to bottom with great nicety, with such nicety, in fact, that these organized instruments of precision must have been sensitive to differences not exceeding one millimeter for every 90 degrees in their course around the real or imaginary axis.

Whether the spirals are due to heliotropism in some plant or to the intelligent act of some animal, no explanation thereof is adequate. Some spirals end abruptly below; others in one or more swellings or enlargements; others in one, two, or three oblique, transverse trunks or "rhizomes." An occasional trunk unites two spirals, and all such are dubbed "twin screws," the screws in each case being reversed—that is, the one left-handed, the other right-handed; the one small, the other large. Many forms noted are of so sensational an order as to preclude them from present mention. As to size, the Devil's corkscrew generally exceeds the height of a tall man, while the ordinary rhizome is about the size of his body.

Some specimens noted were simply gigantic. We have seen them a

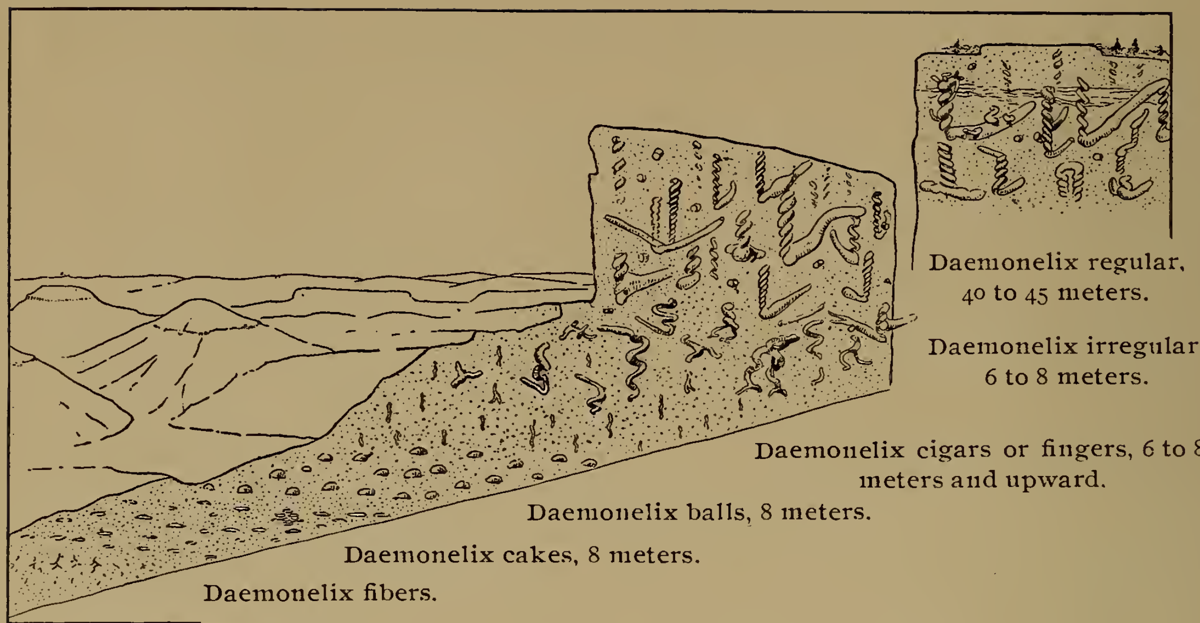


FIGURE 29.—THE SUCCESSION OF DAEMONELIX

As exposed in canyon at Eagle crag, Sioux county, Nebaska, and at Squaw canyon, distant 12 or 15 miles and on a somewhat higher level. The author does not propose this as a phylogeny of the group, although apparently resembling steps in its phylogenetic history. It is presented as a correct statement of the positions of the several forms in the series.

30

cm

31

32

FIGURES 30, 31, and 32.—DAEMONELIX BUDS

These are the ends of spurs and processes found in Daemonelix regular and irregular.

SUCCESSION OF DAEMONELIX AND DAEMONELIX BUDS meter in diameter. We have measured finely preserved rhizomes which equaled 10 meters in length after an unknown amount had been weathered from each extremity.

The superficial structure, like that of every form of the Daemonelix group, consists of the same mat of Daemonelix fibers, already described, surrounding the same core of sand, traversed occasionally by tubules and large tubes.

Microscopically, there is not a suggestion of difference in any of the forms from the first to the last.

One restricted locality near Squaw canyon, because of the perfect preservation of its fossils, makes promise of a solution of the whole question when fully explored. Here the Devil's corkscrews abound in immense numbers. From their spirals and transverse trunks thousands of Daemonelix fibers penetrate the sand in every conceivable direction, crossing, interlacing, intertwining, and uniting spiral to spiral. Great mats of such fibers, called Daemonelix "sheets," extend in horizontal layers across and among the spirals, much as a mat of Spirogyra floats in water.

The whole region around Squaw canyon gives evidence of having been in former times a forest of closely set spirals interlocked by innumerable fibers. It was from data collected at this locality and Eagle Crag that the diagram represented in figure 29 of plate 35 was prepared.

DAEMONELIX "BUDS."

The so-called "buds," which had puzzled the students of former expeditions, were found in place here, and turn out to be the ends of spurs or processes found in Daemonelix, regular and irregular (see plate 35, figures 30, 31, 32).

Superficial Structure of Daemonelix.

The surface structure of the Devil's corkscrew, precisely like that of all preceding forms, is one mat or mass of tubules or fibers. Its external appearance cannot be more aptly likened to anything than a spiral of fine excelsior in a matrix of hydraulic cement. The color of water-lime is almost exactly that of the matrix in which the Devil's corkscrews are found. Should this be further molded and fashioned with wrinkles, corrugations, and folds, as shown in figure 34, plate 36, the similarity of the real and artificial product would be close. The corrugations and wrinkles are parallel to the axis in the rhizome, but transverse, or nearly so, in the spiral, where they are confined to the upper surface, the under surface generally being square cut and smooth. While these markings are invisible in the figures of Daemonelix because of their great reduction, yet they are always present, and are faithfully portrayed in figure 34 and need no further comment.

Great Tubes of Daemonelix.

Matted tubules constitute the visible part of the Daemonelix series, and, because of their perfect fossilization, lend themselves readily to study. Not so the great interior tubes, in which the cells were undoubtedly broken down by decomposition before the replacement by inorganic matter was possible. Accordingly, these tubes have not hitherto yielded to determination under the glass. However, at Squaw canyon, on the last expedition, some specimens were found whose perfection of preservation is beyond praise. On removing the surface mat of tubules the interior of one great rhizome was found to be crowded with hollow, twisting, branching tubes, whose ramifications led apparently to the lesser tubes and thence possibly to the tubules themselves. This at first sight seems to stand in evidence against the burrow theory. The pure white silicious tubes, with diameters varying from 2 to 20 millimeters, with walls scarcely more than one millimeter thick, present a superficial structure with nodular joints and corrugations like the bark of a higher plant (see plate 37, figures 35, 36).

Structurally, the tissues revealed can only be equaled by that of a living plant. Sections across the thin wall show parallel rows of rectangular cells, suggestive of the cork layer of higher plants. Tangential sections show polygonal cells differing in no respect from similar preparations of flowering plants. Apparently all has rotted away but the cork layer. The theory of the fresh-water seaweed, according to this, may yet be sacrificed to that of a higher plant.

Possibly these tubes represent higher plants, which drifted into the lake and upon which grew the Daemonelix fibers encircling them, exactly as is supposed to have been done in the case of the large skeletons and bones found similarly inclosed in Daemonelix.

Minute Structure of the Daemonelix Series.

In studying the microscopic structure of the Daemonelix group, 120 slides cut from every part, of various forms, demonstrate the fact, already stated under each heading, that there is apparent similarity and identity of tissue in all; that the structure, though poorly preserved in some slides, is wanting in none, and that it is cellular but not vascular. This has led the author to believe, and to suggest that these are seaweeds or

FIGURE 33.– CHARACTERISTIC SURFACE STRUCTURE OF DAEMONELIX (natural size)

FIGURE 34.—PORTION OF RHIZOME OF DAEMONELIX REGULAR

This piece is from near the base of the spiral, and shows characteristic fibrous structure and corrugations. Specimen is in National Museum.

SURFACE STRUCTURE AND RHIZOME OF DAEMONELIX

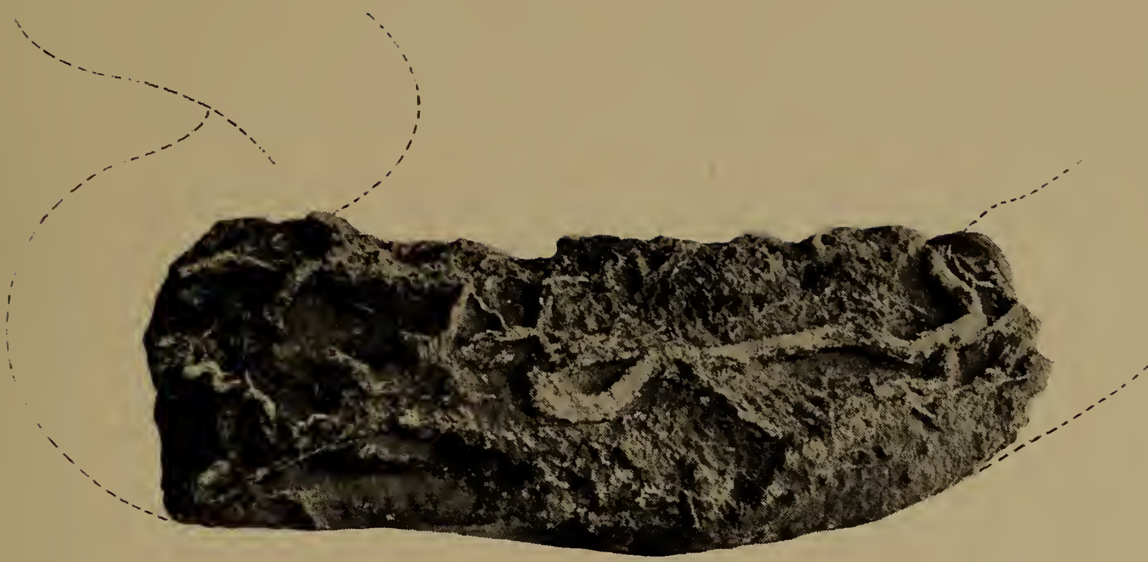


FIGURE 35.—RHIZOME OF DAEMONELIX

This figure represents the left rhizome of figure 25, plate 34, with the surface tubules cut away, thus exposing the great tubes within.

FIGURE 36.—GREAT TUBES OF DAEMONELIX FROM THE ABOVE SPECIMEN

Diameter of largest, 20 millimeters; thickness of wall, from 1 to 2 millimeters. See figure 35. For microscopic structure see figures 46, 47, 48, of plate 39.

RHIZOME AND GREAT TUBES OF DAEMONELIX

FIGURE 37.—CROSS-SECTION DAEMONELIX FIBER

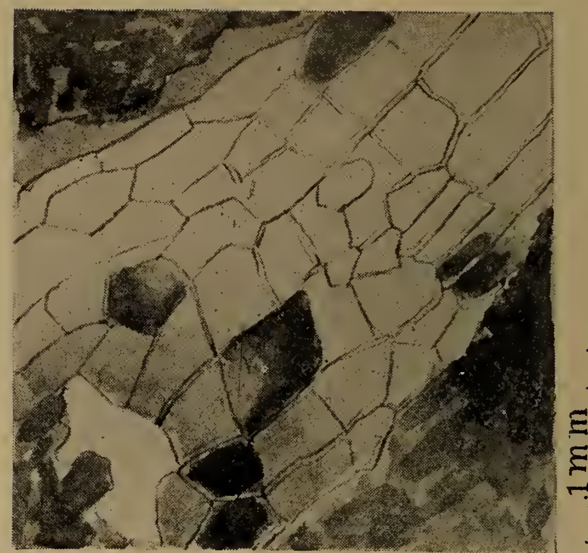


FIGURE 38.—SECTION FROM DAEMONELIX CAKE

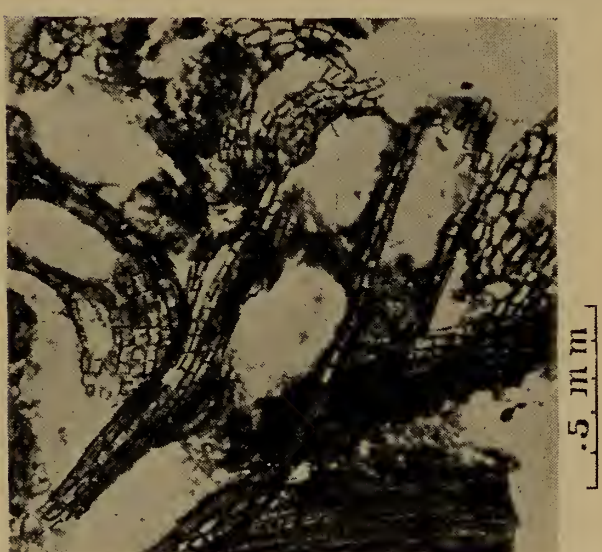


FIGURE 39.—PHOTOMICROGRAPH OF SECTION FROM SURFACE OF DAEMONELIX BALL

(See figures 9, 10, 11, plate 33.)

FIGURE 40.—SECTION FROM DAEMONELIX CIGAR

FIGURE 41.—DAEMONELIX IRREGULAR

a, cross-section of tubules; *b*, longitudinal section; both magnified to same scale.

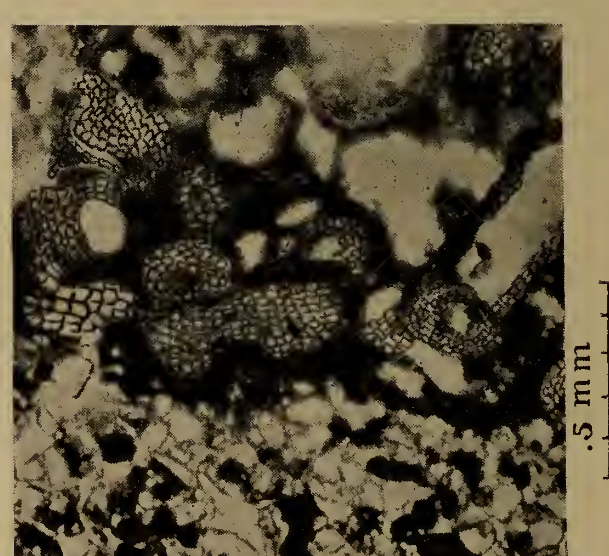


FIGURE 42.—DAEMONELIX REGULAR

Photomicrograph (retouched) of section cut through numerous fibers or tubules.

SECTIONS OF DAEMONELIX

possibly rootlets. Numerous reproductions of these micro-sections are substituted for verbal descriptions (see plates 38 and 39).

In longitudinal sections, average cells vary from 35 to 50 micromillimeters; in cross-section they measure about 10 micromillimeters. The study of the great tubes of Daemonelix made possible by the recent discovery of perfectly preserved specimens threatens to make radical if not revolutionary change—removing Daemonelix altogether from the dominion of the algæ and exalting it to that of the dicotyledons. Though unable to determine positively whether or not these great tubes are an integral part or an accompaniment of Daemonelix, because their branchings and ramifications cannot yet be traced to the surface fibers, yet if they are such, then there is a strong presumption that they are higher plants, in which all has rotted away save the persistent cortical layer (see plate 39, figures 46, 47, 48).

Apparently, then, it would follow that these tubes are roots of higher plants; hence the accompaniment rather than the cause of Daemonelix, which would leave us where we were at first, with the spiral unaccounted for. However, this must not be considered final, for close scrutiny has shown no more connection between the great tubes and the encircling mat of fibers than between the skeletons and their encasements of tubules. Possibly the great tube is but that to and around which the original Daemonelix fibers grew.

The microscopic structure of cross and tangential sections is fairly well represented in figures 46, 47, and 48.

During the coming summer the author will again visit the region of the anomalous Devil's corkscrews, hoping to add thereby link to link until the chain of evidence is made complete.

List of Papers.

The following is a list of the papers published up to the present time on this subject. The first seven are by the author of this article.

Notice of new gigantic Fossils: *Science*, February 19, 1892, 3 figures.

On a new order of gigantic Fossils: *University Studies*, The University of Nebraska, vol. i, no. 4, July, 1892, 35 pp., 18 figures, 6 plates.

Additional Notes on the new Fossil Daemonelix, its Mode of Occurrence, its gross and minute Structure: *University Studies*, The University of Nebraska, vol. ii, no. 1, July, 1894, 32 pp., 1 figure, 12 plates.

Is Daemonelix a Burrow? A reply to Dr Theodore Fuchs: *The American Naturalist*, vol. xxix, June, 1895, 13 pp., 3 figures, 1 plate.

Progress made in the Study of Daemonelix. [Abstract.] *Nebraska Academy of Science*, publication no. v, 1894–'95, 5 pp., 18 figures.

Nature, Structure, and Phylogeny of Daemonelix: *Bulletin of the Geological Society of America*, vol. 8, 1896, pp. 305–314, 9 plates. (Read before the Society December 31, 1896.)

History of the Discovery and Report of Progress made in the Study of Daemonelix: *University Studies*, The University of Nebraska, vol. ii, no. 2, January, 1897.

Notes on the chemical Composition of the silicious Tubes of the Devil's Corkscrew, Daemonelix. Thomas Herbert Marsland: *University Studies*, The University of Nebraska, vol. ii, no. 2, January, 1897.

Remarks on Daemonelix or "Devil's Corkscrews," and allied Fossils. Joseph T. James: *American Geologist*, vol. xv, no. 6, June, 1895, pp. 337–342, plate xi (7 figures), plate xii (3 figures), and 1 figure.

Ueber die Natur von Daemonelix, Barbour: *Annalen k. k. Naturhistorichen Hofmuseums*, Wein, 1893, pp. 91 to 94, by Dr Theodore Fuchs.

A supposed new Order of gigantic Fossils from Nebraska. E. D. Cope: *American Naturalist*, June, 1893.

In the Region of the new Fossil, Daemonelix. Frederick C. Kenyon: *American Naturalist*, March, 1895, 14 pp., 1 cut, 1 plate.

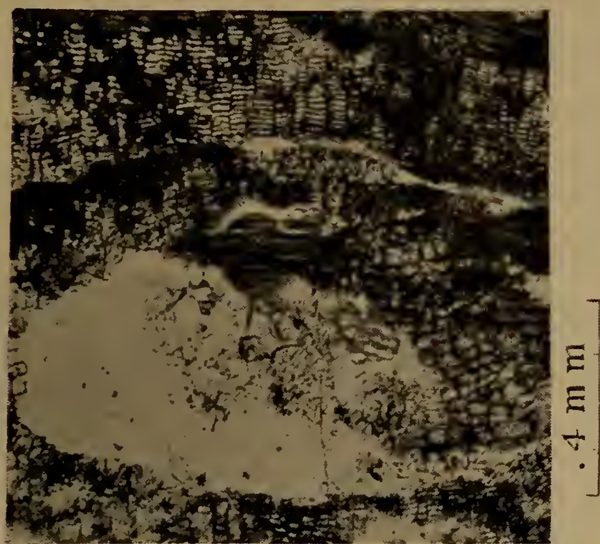


FIGURE 43.—PHOTOMICROGRAPH OF SECTION OF DAEMONELIX REGULAR

Showing two tubes; upper one cut tangentially, the other obliquely.

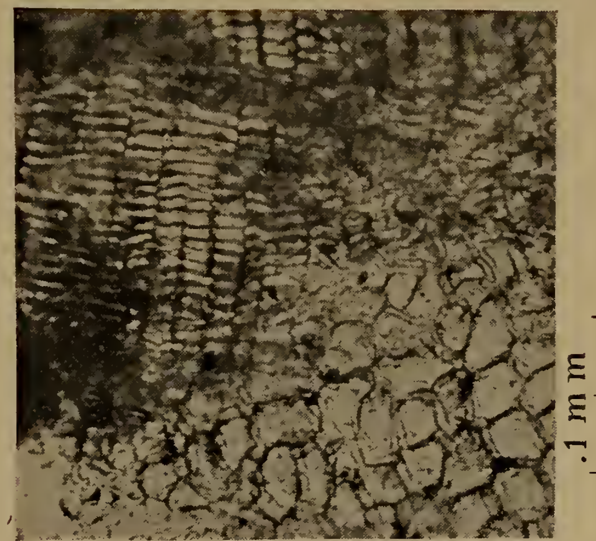


FIGURE 44.—PORTION OF FIGURE 43

Greatly magnified.

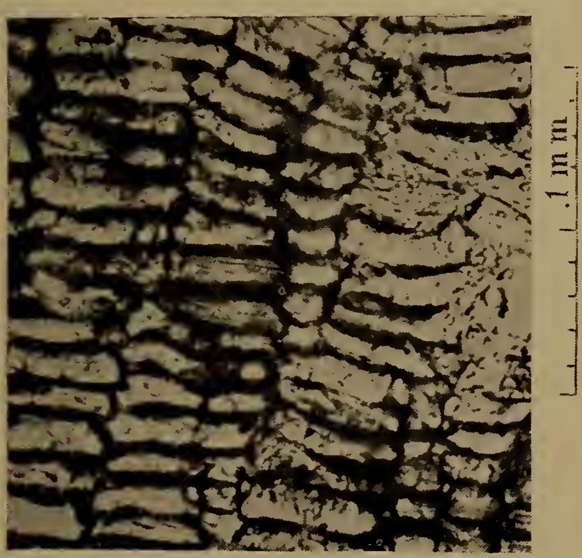


FIGURE 45.—PORTION OF FIGURE 43

More highly magnified.

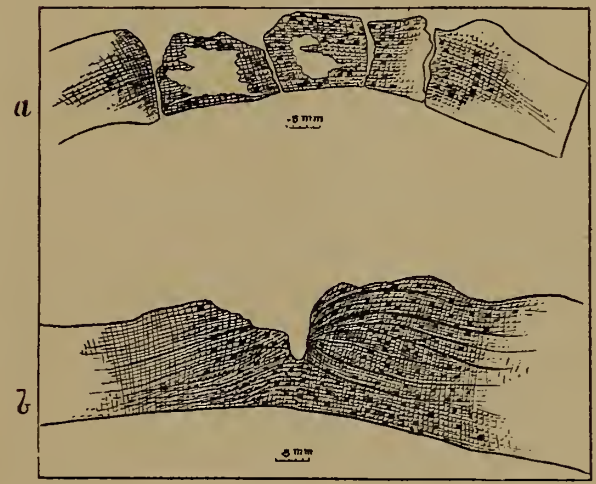


FIGURE 46.—CROSS-SECTIONS OF WALL OF GREAT TUBES OF DAEMONELIX

FIGURE 47.—CROSS-SECTION OF WALL OF GREAT TUBULE OF DAEMONELIX

From retouched photomicrograph.

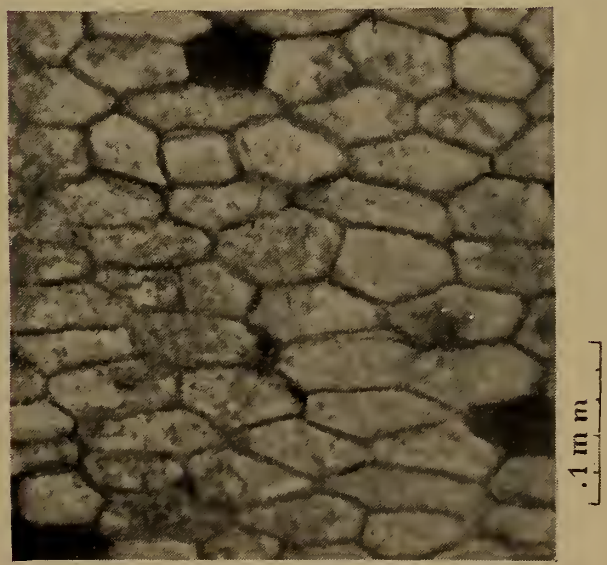


FIGURE 48.—TANGENTIAL SECTION OF GREAT TUBE OF DAEMONELIX

From photomicrograph of same scale as figure 47.

SECTIONS OF DAEMONELIX

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 8, PP. 315-358, PLS. 40-50 APRIL 15, 1897

UPPER CRETACEOUS FORMATIONS OF NEW JERSEY, DELAWARE, AND MARYLAND

BY WILLIAM BULLOCK CLARK, WITH THE COLLABORATION OF R. M. BAGG AND GEORGE B. SHATTUCK

(*Read before the Society December 31, 1896*)

CONTENTS

Introduction.

The present paper presents an outline of the results obtained by the authors in a study of the post-Potomac Cretaceous formations in the states of New Jersey, Delaware, and Maryland. The work constitutes a part of a series of investigations which has embraced the whole sequence of Cretaceous-Tertiary formations throughout this area, and which is still in progress. Considerable advance has already been made both in the interpretation and cartographic representation of the other divisions of the series, and they will shortly be made the subject of further contributions.

DEEP CUT IN THE DELAWARE AND CHESAPEAKE CANAL, DELAWARE

Showing erosion in Matawan formation. Potomac formation at the base.

The investigations have been conducted during the past five years under the auspices of the United States Geological Survey and the state surveys of New Jersey and Maryland. The boundaries of the formations have been platted upon the United States Geological Survey atlas sheets, the areal mapping having been done upon the scale of one mile to the inch throughout the entire district with the exception of Delaware and the eastern shore of Maryland.

Somewhat extensive changes have been made in the classification of formations adopted by previous writers and some modifications in the use of the formation names employed by the authors in earlier articles. This has been the result of more complete knowledge of the formations, based upon later work in Delaware and Maryland, and has shown that certain divisions which are important in one area lose their identity and become merged with contiguous members of the series in other areas, so that they can no longer be stratigraphically or faunally separated. The major divisions which have now been adopted are capable of application to the deposits throughout the entire region from the Raritan to the Potomac, and are the only ones which can be so employed with satisfactory results.

The Upper Cretaceous formations of New Jersey, Delaware, and Maryland here classified and mapped constitute a circumscribed province, which is represented in a few isolated occurrences off the New England coast and at one locality in Massachusetts. South of the Potomac the strata become covered by a mantle of later deposits. The records of certain well-borings point to the occurrence of Cretaceous deposits in eastern Virginia, but their character and extent have not been fully determined. Similar deposits occur in surface exposures in the Carolinas, but they have not as yet been sufficiently studied to show to what extent they may be correlated with the formations of the northern Atlantic belt.

Historical Sketch.

The Cretaceous formations of the Atlantic Coastal plain have been the subject of frequent discussions throughout the present century, while scattered references to the district are found in the works of still earlier date.

The first contribution to the subject of Coastal Plain geology which is worthy of special mention is found in the publications of Professor Peter Kalm,* who was sent out to America in 1749 under the auspices of the

* En Resa til Norra America, 8vo, 3 vols., 1753–'61, Stockholm. Translations in English by J. R. Foster; 1st ed., 1770–'71; 2d ed., 1772; another edition in J. Pinkerton's voyages, vol. 13, 1812; in German by J. H. Murray, 1754-'64; in French by L. W. Marchand, 1859.

Royal Academy of Sciences of Sweden to make a study of the various branches of natural history in this country. He visited the northern part of the district now under consideration and recorded many observations of interest.

In 1777 Dr Johann David Schoepf,* of Germany, visited America in order to study the geological features of the eastern portion of the continent. His observations and comparisons of the Coastal Plain formations mark considerable advance over those of Kalm. The importance of his investigations have not been very generally recognized by later writers, but he showed a remarkably keen insight into the geology of eastern America, which was lacking on the part of some of his successors.

The first attempt at a correlation of the deposits of the Coastal plain with the geological column then established in Europe was made by William Maclure,† in 1809, in his "Observations on the Geology of the United States." In this publication the coastal deposits are collectively referred to the "Alluvial formation," the fourth of the main divisions of geological strata proposed by Werner. The work was subsequently revised and enlarged, appearing in book form in 1817.‡

A few years subsequent to the appearance of Maclure's articles, H. H. Hayden § published a volume of "Geological Essays," in which an explanation is given of the great accumulation of "alluvial deposits" in the eastern and southern portions of the United States, and the stratigraphy of the region is described in much greater detail than by his predecessors. Reference is made to the wide distribution of fossil shells and vertebrate remains, and many localities are cited.

A second work of the same general character, so far as it relates to the geology, was published somewhat later by Parker Cleveland.|| It is entitled "An Elementary Treatise on Mineralogy and Geology," and on page 785, under "Remarks on the Geology of the United States Explanatory of the Subjoined Geological Map," the author defines the limits of the "alluvial deposits," and in general terms describes their lithological character.

Samuel Akerly,¶ in an essay published in New York in 1820, discusses the "alluvial deposits" of northern New Jersey. In this paper the marl

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* Beitrage zur mineralogischen Kenntniss des östlichen Theils von Nord Amerika und seiner Gebürge, 8vo, 1787, 194 pp., Erlangen.

† Amer. Phil. Soc. Trans., vol. 6, 1809, pp. 411–428. Translation in Journal de Physique, vol. 69, 1809, pp. 204–213, and vol. 72, 1811, pp. 137, 138.

‡ Philadelphia, 8vo, 130 pp.; also in Amer. Phil. Soc. Trans., new series, vol. 1, 1817, pp. 1–92, and Leonard's Zeitschrift, band 1, 1826, pp. 124–138.

§ Geological Essays, etc., Baltimore, 1820, 8vo, vol. viii, 412 pp.

|| An Elementary Treatise on Mineralogy and Geology, 1822.

¶ An Essay on the Geology of the Hudson River and the Adjacent Regions, etc., New York, 1820, 12mo, 69 pp. and one plate.

beds, together with some of their fossils, are described, but no evidence is adduced that the author recognized their taxonomic position.

James Pierce,* in a "Notice of the Alluvial District of New Jersey," published a few years subsequently, describes the marl deposits of Monmouth county in that state.

Professor John Finch,† of England, was the first to recognize, when visiting this country in 1824, that the Coastal Plain deposits represented more than a single horizon. His contribution on this subject contained the first attempt at a correlation of the several deposits of the Coastal plain with other areas, and although thus early in the study of the subject minute comparisons, which the facts did not warrant, were made, yet the knowledge of Atlantic Coastal Plain stratigraphy was materially advanced. In this article he says:

> "I wish to suggest that what is termed the alluvial formation in the geological maps of Messrs Maclure and Cleveland is identical and contemporaneous with the newer Secondary and Tertiary formations of France, England, Spain, Germany, Italy, Hungary, Poland, Iceland, Egypt, and Hindostan."

During the year 1825 Jer. Van Rensselaer ‡ delivered a course of lectures in the New York Atheneum, on geology, that were subsequently published in book form. The author adopted the classification proposed by Finch, although he confined his description to the northern representatives of the Cretaceous-Tertiary series.

The credit for the first definite recognition of the Cretaceous deposits of the Atlantic Coastal plain must be ascribed to Professor Lardner Vanuxem. The results of his observations were placed in the hands of his friend, Dr S. G. Morton,§ for publication in the Journal of the Academy of Natural Sciences of Philadelphia. His views were again stated under his own signature in the American Journal of Science,|| in which reference is made to the earlier publication.

In the years immediately succeeding the publication of Professor Vanuxem's articles several contributions were made by Dr S. G. Morton, both in the Journal of the Philadelphia Academy of Natural Sciences and the American Journal of Science, upon the organic remains of the Cretaceous deposits, and these were finally embodied in 1834 in an important work entitled "Synopsis of the Organic Remains of the Cretaceous Group of the United States."¶

*Amer. Jour. Sci., vol. 6, 1823, pp. 237–242.

†Amer. Jour. Sci., vol. 7, 1824, pp. 31–43.

‡Lectures on Geology, 1825, 8vo, 358 pp.

§Jour. Acad. Nat. Sci. Philadelphia, vol. 6, 1829, pp. 59–71.

||Amer. Jour. Sci., vol. 16, 1829, pp. 254–256.

¶Philadelphia, 1834, 8vo, pp. —, plates.

In 1835* Dr Morton proposed a general division of the Cretaceous of the United States into three groups, the uppermost of which, however, is now generally regarded as belonging to the Tertiary. His views on this point were again stated in 1842.†

During the decade 1830 to 1840 the three states of New Jersey, Delaware, and Maryland established state geological surveys under the direction respectively of H. D. Rogers, J. C. Booth, and J. T. Ducatel.

The first attempt at a local and detailed differentiation of the Cretaceous deposits in the northern Atlantic Coastal plain appears in Professor Rogers' first report, published in 1836, and is more elaborated in his final report, published in 1840, in which he recognizes the following formations, beginning with the lowest: *Clays and Sand*, *Greensand*, *Limestone*, *Ferruginous Sand*, *Brown Sandstone*. Although these several divisions were not clearly defined, and widely different materials were included in the same formation, yet the easterly dip of the strata was observed and the broader distinctions in the formation were recognized.

Ducatel, in his annual report as state geologist for 1837, records the presence of Cretaceous deposits along the Sassafras river on the eastern shore of Maryland, while Booth, in his "Memoir of the Geological Survey of the state of Delaware," published in 1841, which was based upon his two annual reports for the years 1837 and 1838, divides the "Upper Secondary" of his state into the "Red Clay" and the "Greensand" formations.

The visit of Charles Lyell to the United States in 1841 was an important event in the history of Coastal Plain geology. The inspiring presence of the author of the epoch-making "Principles of Geology," coupled with his wide knowledge regarding similar deposits in Europe, led to renewed activities in the field of Coastal Plain geology and the correct interpretation, under his leadership, of many points which had up to that time been but imperfectly understood. Although Lyell's work had reference more to the Tertiary than the Cretaceous, yet his observations in several instances were turned either directly or indirectly to the latter. In his contributions ‡ he correlated the American Cretaceous rocks with the divisions between the Gault and the Maestricht of Europe, and also showed that Morton's upper division of the Cretaceous was of Eocene age.

Dr T. A. Conrad § in 1848 first suggested that the upper portion of

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*Amer. Jour. Sci., vol. 28, 1835, pp. 276–278.

†Jour. Acad. Nat. Sci. Philadelphia, vol. 8, 1842, pp. 207–227.

‡Quart. Jour. Geol. Soc. London, vol. 1, 1843, pp. 55–60; Proc. Geol. Soc. London, vol. 4, 1845, pp. 31–33; Amer. Jour. Sci., 1844, vol. 47, pp. 213, 214.

§Jour. Acad. Nat. Sci. Philadelphia, new series, vol. 1, 1848, p. 129; Proc. Acad. Nat. Sci. Philadelphia, vol. 17, 1865, pp. 71, 72.

the greensand series of New Jersey was of later age than the Cretaceous, a conclusion which he more fully elaborated at a later date.

The earlier state surveys having come to an end, a considerable period elapsed during which the several states of the district under consideration were without official organizations. In 1847 Maryland made provision for a state agricultural chemist, while a few years subsequently to this the state of New Jersey established a second geological survey. Under the direction of the first agricultural chemist, Dr James Higgins, little geological work was attempted in Maryland, but the survey of New Jersey, under the direction of William Kitchell, had as assistant geologist George H. Cook, who was later to become himself the head of the survey, and in that capacity to add more to the knowledge of the stratigraphy of the Cretaceous formations than any one who had preceded him. In the first of Kitchell's reports for the year 1854, Cook already recognized the fact that "there are three distinct beds of marl." These three marl beds were examined by him with much care and the characteristic features of each portion of them described in the later Survey reports.

During the decade 1860 to 1870 many special articles dealing with the paleontology of the several formations under consideration appeared, although most of these publications are confined to the New Jersey portion of the region. Conrad, Cope, Marsh, Credner, Gabb, Meek, and others contributed to the same, with the result that a fuller knowledge was gained of the paleontology of the New Jersey area than of any other Cretaceous district throughout the Coastal plain.

In 1860 Dr Philip T. Tyson, who had been appointed state agricultural chemist to succeed Dr James Higgins, published his first annual report upon the geology of Maryland, in which he discusses the Cretaceous formations of that state. His second and last report appeared in 1862. Although he recognized the presence of some of the New Jersey divisions upon the eastern shore of Maryland, he made little attempt at their accurate discrimination.

Professor George H. Cook, having been appointed state geologist of New Jersey, presented his first report of progress for the year 1865. Reports were published during successive years until his death, in 1889. Associated with him in much of his work was Professor J. C. Smock, the present head of the survey. It is unnecessary at this time to view the advance made each year or to refer in detail to each report. In 1868 a general volume appeared, entitled "Geology of New Jersey," in which an extensive description of the Coastal Plain deposits is found. In this report Professor Cook divided the Cretaceous deposits as follows:

Upper marl bed	Blue marl. Ash marl. Green marl.
Yellow sand.	
Middle marl bed	Yellow limestone and lime-sand. Shell layer. Green marl. Chocolate marl.
Red sand	Indurated green earth. Red sand. Dark micaceous clay.
Lower marl bed	Marl and clay. Blue shell marl. Sand marl.
Clay marls	Laminated sands. Clay containing greensand.
Plastic clay	Lignite. Potter's clay. Lignite.

In 1870 Dr Hermann Credner,* above referred to, published the results of his observations upon the New Jersey Cretaceous. He regarded the deposits as closely related to the upper Cretaceous of Europe, and mentioned upward of 40 species of fossils as being identical with those of the Senonian of northern Europe.

In later years Professor R. P. Whitfield has been engaged in an exhaustive study of the fauna of the Cretaceous belt of New Jersey. Two monographs of great importance have been published. The first, entitled "The Brachiopoda and Lamellibranchiata of the Raritan Clays and Greensand Marls of New Jersey," appeared in 1885, and the second, "The Gasteropoda and Cephalopoda of the Raritan Clays and Greensand Marls of New Jersey," in 1892.

Dr C. A. White,† in an admirable essay upon "The Cretaceous of North America," published in 1891, describes the formations now under consideration and discusses the evidence for their correlation with the deposits of other areas. He does not attempt to separate the individual members of the series, however, beyond the reference of the upper division to the Eocene, as was also done by the senior author of this paper in his report upon "The Eocene of the United States." ‡

Investigations embracing portions of the Cretaceous series of the northern Atlantic Coastal plain have been in progress at times during later years by Uhler, § Darton, ‖ and Hollick. ¶ Messrs Uhler and Darton have confined their investigations almost exclusively to the Cretaceous

* Zeitschrift der Deutschen Geol. Gesell. Jahr., 1870, pp. 191–257, and map.
† Bulletin 82 of the U. S. Geological Survey, 1891, p. 273.
‡ Bulletin 83 of the U. S. Geological Survey, 1891, p. 173.
§ Trans. Md. Acad. Sci., vol. 1, 1889–'90, pp. 10–32, 45–72, 97–105.
‖ Bulletin Geol. Soc. Amer., vol. 2, 1891, pp. 438, 439; Trans. Amer. Inst. Min. Eng., 1894.
¶ Trans. New York Acad. Sci., 1895, pp. 1–10.

BLUFF AT ATLANTIC HIGHLANDS, NEW JERSEY

Looking south; showing Hazlet sands of Matawan formation overlain by Monmouth formation.

upon the western shore of Maryland, Darton having described a considerable portion of the upper Cretaceous of this area under the name of the Severn formation, while the observations of Mr Hollick have chiefly embraced the deposits in northern New Jersey beneath those now under consideration, although the basal members of the upper Cretaceous in this area, as well as the transported fragments of the same formations upon Staten island and Long island, have been discussed.

During recent years Mr Lewis Woolman,* of Philadelphia, has collected a large amount of valuable information regarding the well-borings throughout the northern Atlantic Coastal plain. This data is of much value to the field geologist in helping him to control his conclusions. Mr Woolman's records have been frequently consulted, although the authors have often differed from him in the interpretation of the data.

The later history of investigation of the Upper Cretaceous formations in this district is confined largely to the work carried on under the direction of the senior author by the instructors and students of the Johns Hopkins University. Several papers † have already appeared and others are in course of preparation, in which more detailed discussions will be found regarding both the geological and paleontological aspects of the subject.

Topographic Features.

The Upper Cretaceous formations constitute a part of the great area of lowland bordering the Atlantic coast of North America and known as the Coastal plain. This plain extends with constantly narrowing limits from the southern Atlantic states across the area now under consideration, beyond which its continuity becomes broken, although represented in the southern portions of New England and in the various islands along the coast. The width of the northern Coastal plain varies from somewhat over 100 miles in central Maryland to scarcely 25 miles in eastern New Jersey.

The Upper Cretaceous formations occupy a belt within the Coastal plain which extends from northeast to southwest and which is separated by a tract some 10 or 15 miles in width, composed of Lower Cretaceous deposits, from the Piedmont plateau. This belt of Upper Cretaceous strata varies in width from about 25 miles in eastern New Jersey to barely a mile in southern Maryland. Its more unyielding deposits have produced a ridge of high land, which, with varying elevations, extends along

*Annual reports of the state geologist of New Jersey, 1889 to 1895.

† Rept. State Geologist N. J., 1892, pp. 167–245; ditto, 1893, 1894, pp. 329–355; Jour. Geol., vol. ii, 1894, pp. 161–177; Bull. Geol. Soc. Amer., vol. 6, 1895, pp. 479–482; Johns Hopkins Univ. Circulars, vol. 8, 1889, pp. 20, 21; ibid., vol. 15, 1895, pp. 3, 10–12, 14, 15, 17.

the center of the belt. This ridge forms an escarpment toward the west, but generally declines gradually seaward.

The *Cretaceous escarpment*, as it may properly be called, stretches across New Jersey from the vicinity of Sandy Hook to the head of Delaware bay, and forms for much of the distance the divide between the streams entering the Atlantic ocean on the east and the Raritan and Delaware rivers on the west. Beginning on the prominent headland of the Highlands of Navesink, which rise to 276 feet, it extends westward (plate 49, figure 2) as a clearly defined ridge (south of Keyport reaching its greatest height at 391 feet) for a distance of about 15 miles to the vicinity of Morganville, beyond which the range broadens, and with a general elevation of 200 feet continues to Freehold. From this point the ridge turns to the southwestward as far as Clarksburg, in the vicinity of which is a group of hills more than 300 feet in height, Pine hill being 372 feet above sealevel.

From the Pine Hill region the Cretaceous escarpment extends southward into central New Jersey, being clearly shown in such points as Red hill (234 feet), Arneys mount (230 feet), mount Holly (180 feet), and mount Laurel (173 feet), although the elevation of the country does not generally exceed 150 feet. In the valley of Rancocas creek is an area of lowland which falls considerably below 50 feet and which marks the line of a depressed belt crossing southern New Jersey. To the south of mount Laurel the escarpment is less clearly shown, although appearing at Haddon heights, Woodbury heights (the latter reaching 161 feet), and at some other points. To the south of Woodbury heights, with the exception of an area of highland to the east of Swedesboro, the escarpment is less pronounced, while throughout Salem county, in southern New Jersey, it is hardly apparent.

To the south of the Delaware river in the state of Delaware and upon the eastern shore of Maryland the escarpment practically disappears, but upon the western shore of the Chesapeake, throughout Anne Arundel and Prince Georges counties, extending nearly the entire distance to the Potomac river, the escarpment is clearly shown, but nowhere rising into the marked ridge which characterizes it in central and northern New Jersey. In Anne Arundel county it appears in several isolated hills, which, however, are in part made up of the overlying Eocene deposits. Such elevations are seen at mount Misery on the Severn river and to the east and south of Millersville. Beyond the Patuxent, in Prince Georges county, the escarpment is somewhat broken, but appears to the southeast of the Baltimore and Potomac railroad. Farther to the south it skirts the shore of the Anacostia river, and thence following the line of the Potomac river valley continues as far as Piscataway creek.

The escarpment throughout the area described is determined in part by the character of the Upper Cretaceous strata and in part by underlying and overlying formations. The great difference in the volume of the Upper Cretaceous deposits in passing from the northern to the southern portions of the district is very marked, and the strata become a constantly less important factor in determining the topography.

The escarpment faces the more readily eroded deposits of the Lower Cretaceous, and, throughout the larger portion of New Jersey, the lowest member of the Upper Cretaceous series as well. This formation, however, rises also into the base of the escarpment, although the escarpment proper is made up of the higher members of the series and the formations which overlie them. As these upper members gradually disappear to the southward the Tertiary becomes a more and more prominent factor in the formation of the escarpment, which in Maryland is largely to be accounted for upon these grounds. In no portion of Maryland, not even upon the western shore, where the country is much higher than upon the eastern shore of the Chesapeake, are there elevations in any way comparable with those found in northern New Jersey; yet the edge of the escarpment, especially to the south of the Severn river, frequently reaches a height of 200 feet, and does not fall much below that elevation even in the valley of the Potomac river.

The streams show a marked difference in their valley characters, dependent on whether they drain directly to the Atlantic by easterly and southerly courses, or whether they flow to the west toward the fall-line. The valleys of the Atlantic drainage are broad, the land rising gently on either bank, while the channels of the streams flowing toward the fall-line have much steeper slopes and are generally U-shaped. An explanation for this may be found in the stratigraphy of the region, since the strata dip slightly to the southeastward, so that the streams flowing in that direction follow the slope of the beds, while those flowing to the northward must cut across their upturned edges. As the beds vary in hardness the widening of the channel must be retarded by the hardest layers.

Description of the Formations.

GENERAL STATEMENT.

The geological formations of the Coastal area of New Jersey, Delaware, and Maryland represent a nearly complete sequence from the base of the Cretaceous to the Pleistocene. They form a series of thin sheets which are inclined slightly to the southeastward, so that successively later formations are encountered in crossing the district in that direction. Variations in the angle and direction of tilting and later denudation have occasioned in many instances a marked divergence from these normal conditions, and detached outcrops are at times found far removed from the main body of the deposits. The formations discussed in the following pages are as follows:

Eocene	Shark River formation.	
Upper Cretaceous	Manasquan formation.	
	Rancocas formation	Vincentown lime-sands. Sewell marls.
	Monmouth formation	Redbank sands. Navesink marls. Mount Laurel sands.
	Matawan formation	Hazlet sands. Crosswicks clays.

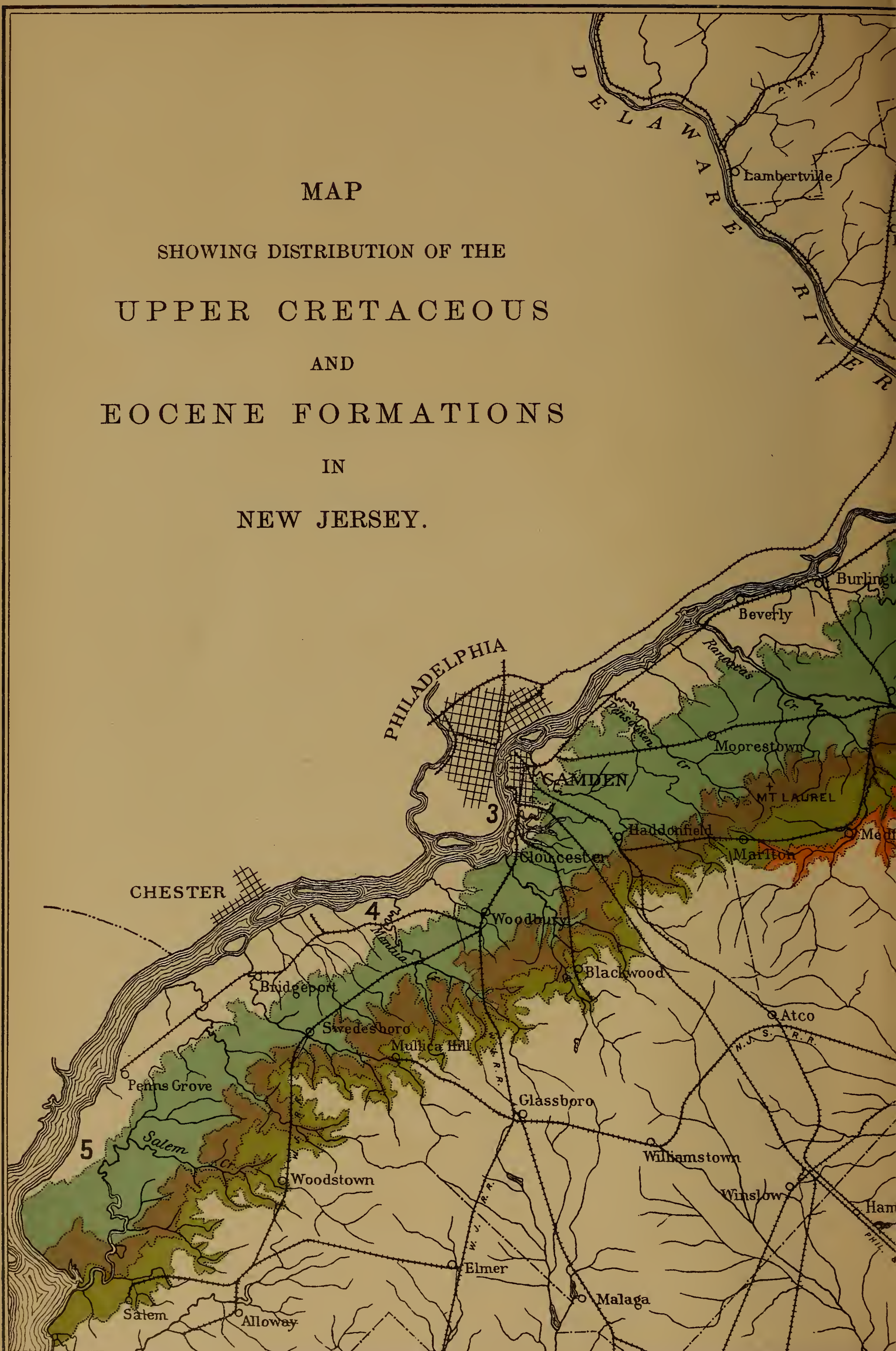
Glauconite characterizes all of the deposits from the base of the Matawan to and including the Shark River formation, and appears in varying amounts and under different conditions in the several formations. Their lithologic features are in general sufficiently distinctive and persistent to be of the greatest value in the determination of the horizons. The presence of greensand *in situ* has not been observed in the Raritan formation which underlies, nor in the Chesapeake formation which overlies this sequence of glauconitic deposits.

MATAWAN FORMATION.

Name.—The Matawan formation receives its name from Matawan creek, in Monmouth county, New Jersey, where the deposits of this horizon are typically developed. The name was originally given by the senior author of this paper in an article published in the Journal of Geology,* and was made to embrace in a general way the division to which Professor Cook had earlier assigned the name of Clay Marls, although his characterization of the deposits was not complete and was confined almost entirely to their development in northern New Jersey. Furthermore, the term Clay Marls does not adequately describe the deposits, although beds of that nature are found at various horizons, particularly in the lower portions of the formation.

Areal distribution.—The Matawan formation extends as an irregular belt from the shores of Raritan bay to the Potomac river. In the extreme north, in Monmouth county, New Jersey, the width of the band is from 9 to 12 miles, but in proceeding southward it gradually narrows, with some exceptions due to the topography of the land, and in the southern counties of New Jersey does not exceed 6 miles in width. Upon the western shore of the Delaware river, in the state of Delaware, it has still further narrowed until it has a width of scarcely more than

* Vol. ii, 1894, p. 163.


MAP
SHOWING DISTRIBUTION OF THE
UPPER CRETACEOUS
AND
EOCENE FORMATIONS
IN
NEW JERSEY.
DELAWARE RIVER
P. R. R.
Lambertville
Burlington
Beverly
Rancocas Cr.
PHILADELPHIA
Pensauken Cr.
Moorestown
CAMDEN
MT LAUREL
3
Haddonfield
Marlton
Gloucester
CHESTER
4
Mantua
Woodbury
Blackwood
Bridgeport
Atco
N. J. S. R. R.
Swedesboro
Mullica Hill
W. J. R. R.
Penns Grove
Glassboro
5
Salem Cr.
Williamstown
Woodstown
Winslow
Elmer
Malaga
Salem
Alloway

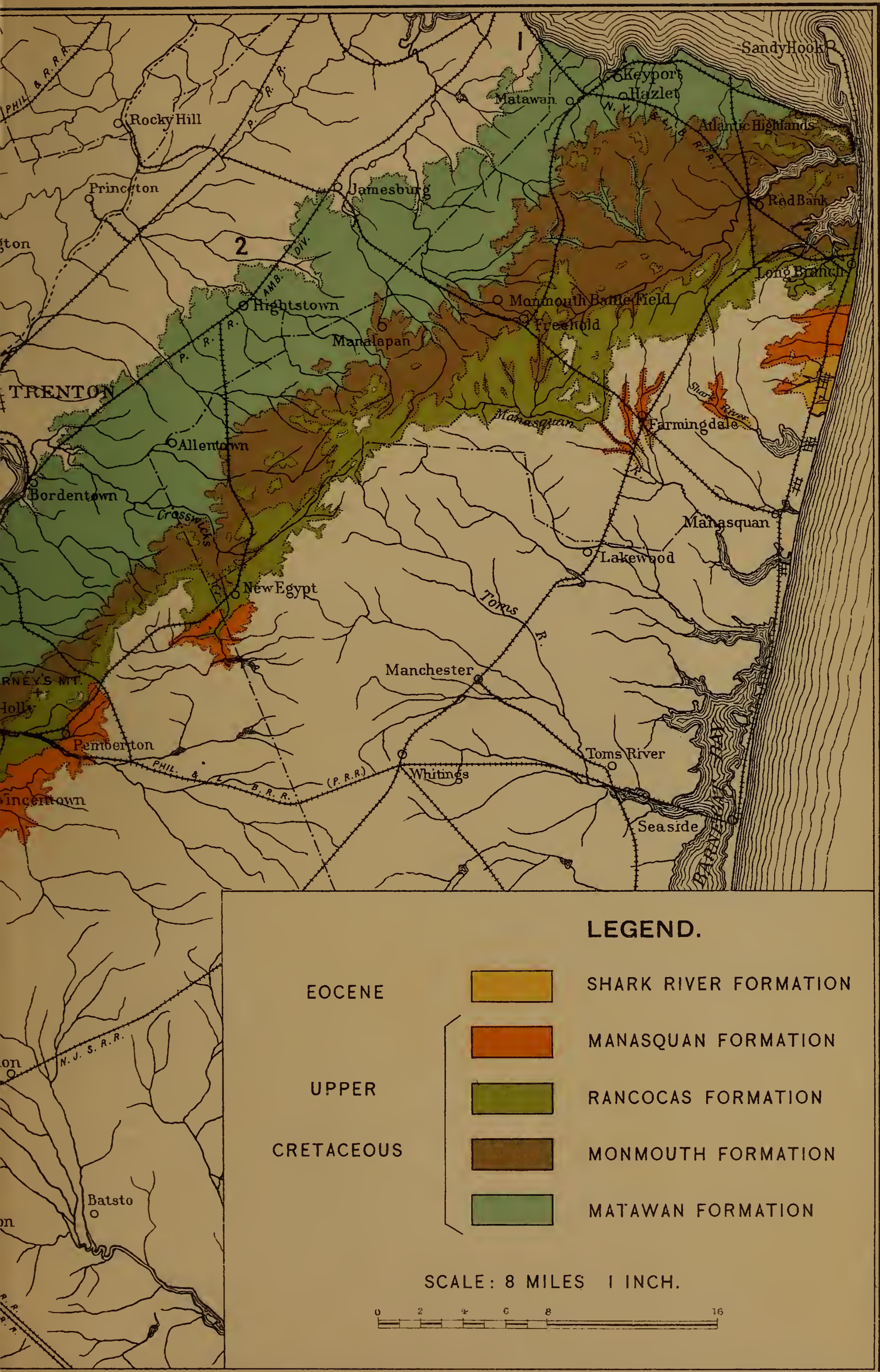
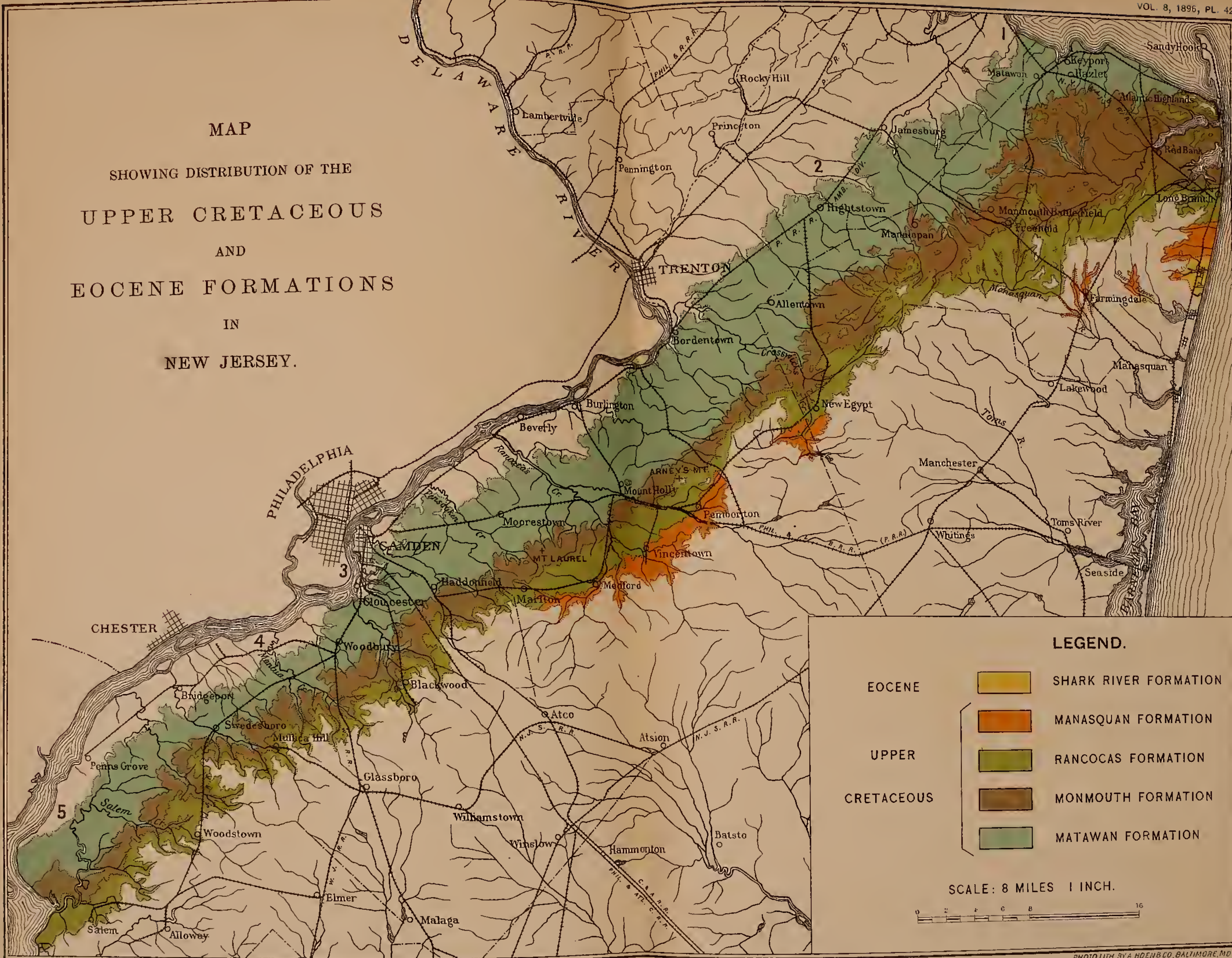


PHOTO LITH. BY A. HOEN & CO., BALTIMORE, MD

D EOCENE FORMATIONS IN NEW JERSEY



DISTRIBUTION OF THE UPPER CRETACEOUS AND EOCENE FORMATIONS IN NEW JERSEY

2 or 3 miles. Farther to the south, upon the eastern shore of Maryland, it again slightly broadens, and below the mouth of the Sassafras river has a width of some 5 miles. Upon the western shore of Maryland, in Anne Arundel county, its areal distribution is very variable on account of the extremely broken character of the country, but upon the whole has narrowed in extent as compared with the eastern side of the Chesapeake. In places it reaches 3 or 4 miles in width, but more often is less than 1 mile. Farther to the south, in Prince George's county, it is found simply as a narrow strip, at no point reaching a mile in width, and continues in and out along the slopes of the hills, following the contours of the valleys.

Character of materials.—The deposits of the Matawan formation are very variable. Sands and clays predominate. The sands are at times white and coarse, but are more commonly fine grained and deeply colored by iron, which may even cause local induration, or they are mixed with argillaceous materials, forming either a silvery micaceous sand or a chocolate colored marl, in the latter case grains of glauconite being present in greater or less amounts.

The clays are generally black or drab in color, but may locally carry seams and pockets of glauconite, which give it a greenish tinge. At a few points the deposits are somewhat calcareous as the result of their molluscan contents, but in general the beds are not highly fossiliferous.

Strike, dip, thickness.—The strike of the beds is north-northeast to south-southwest, with apparent local variations where the overlying Cretaceous and Tertiary deposits have been either more largely eroded or more fully preserved, causing the line of outcrop to be at times diverted at a considerable angle from the normal strike. This is seen in northern Monmouth county where the stripping off of the cover of the later Cretaceous formations has caused the widening out of the belt of the underlying Matawan and has turned the line of contact very nearly at right angles to the strike. Such variations may be easily detected when the normal dip is present, but may lead to considerable complication when it is not.

The dip of the formation is upon the average about 25 feet in the mile, but locally it may be either slightly increased above or slightly decreased below this amount. The determination of the dip depends for the most part upon records afforded by well-borings, although some of the natural section lines, especially in the Mount Pleasant hills, New Jersey, and along the Severn river, Maryland, afford valuable data.

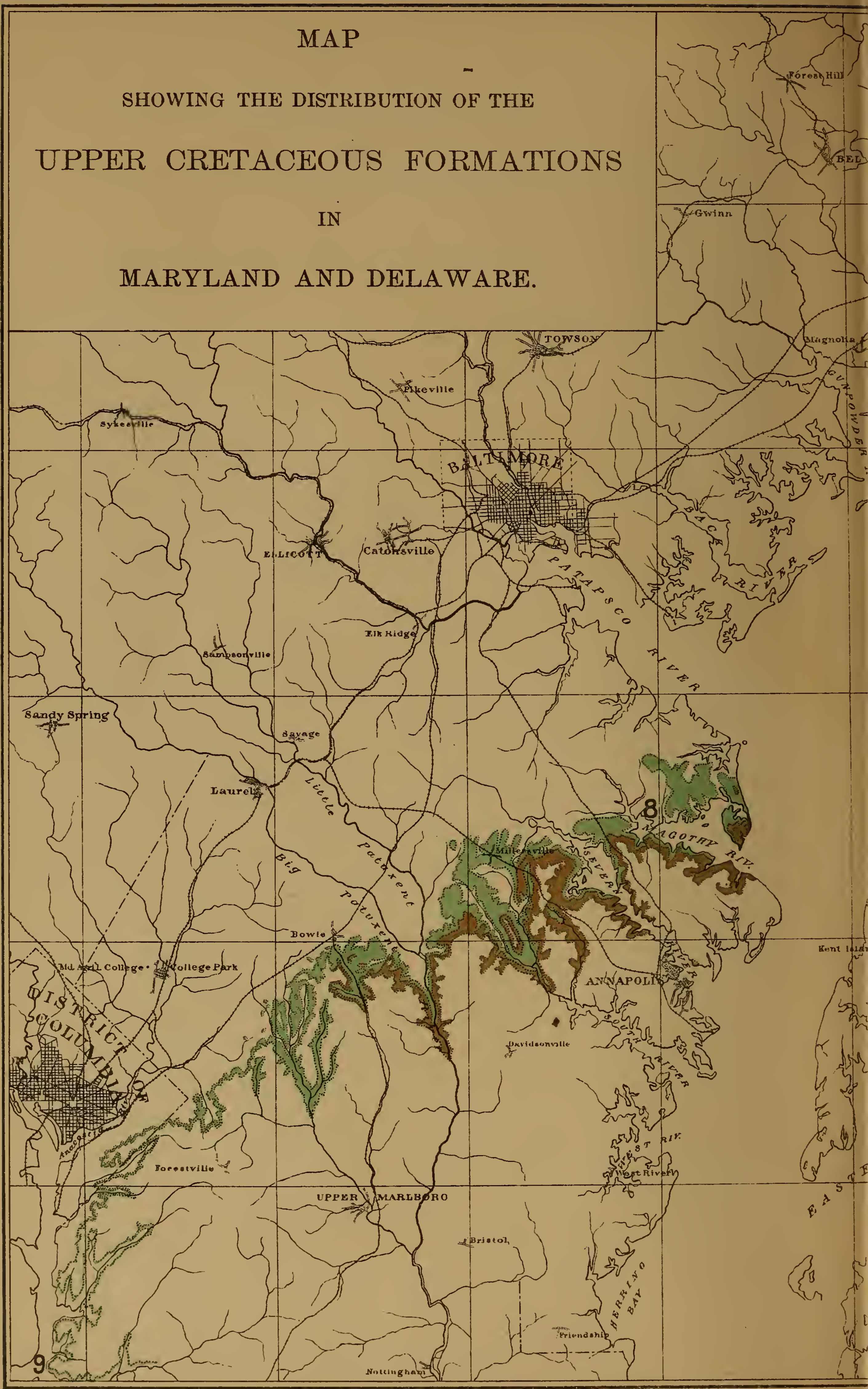
The thickness of the Matawan formation is very variable, but in general becomes gradually reduced in passing from the northern to the southern portions of its area of outcrop. In Monmouth county it has been found to be about 275 feet, with a gradual thickening toward the southeastward, as is shown in the wells at Asbury Park, where it has a thickness of about 400 feet. Along the strike toward the south it is already less than 200 feet in thickness in northern Burlington county, while in the region directly to the east of Philadelphia and Camden it has further declined to 125 feet. In Gloucester county it thickens again, having been found in well-borings to exceed 175 feet in places. Farther to the south it thins and in the vicinity of Salem has declined to 80 feet. In the state of Delaware it is not over 60 feet, but it gradually thickens through the eastern counties of Maryland until, near the mouth of Sassafras river, it again exceeds 100 feet in thickness. In eastern Anne Arundel, upon the western shore of Chesapeake bay, its thickness has already declined to 60 feet, while in the region farther south, in western Anne Arundel and Prince George's counties, it has still further diminished, until at the Fort Washington bluffs it is but little more than 15 feet thick. Its last appearance to the southward, so far as observed, is in the valley of Piscataway creek. Upon the opposite side of the Potomac the Eocene is found resting directly upon the Potomac.

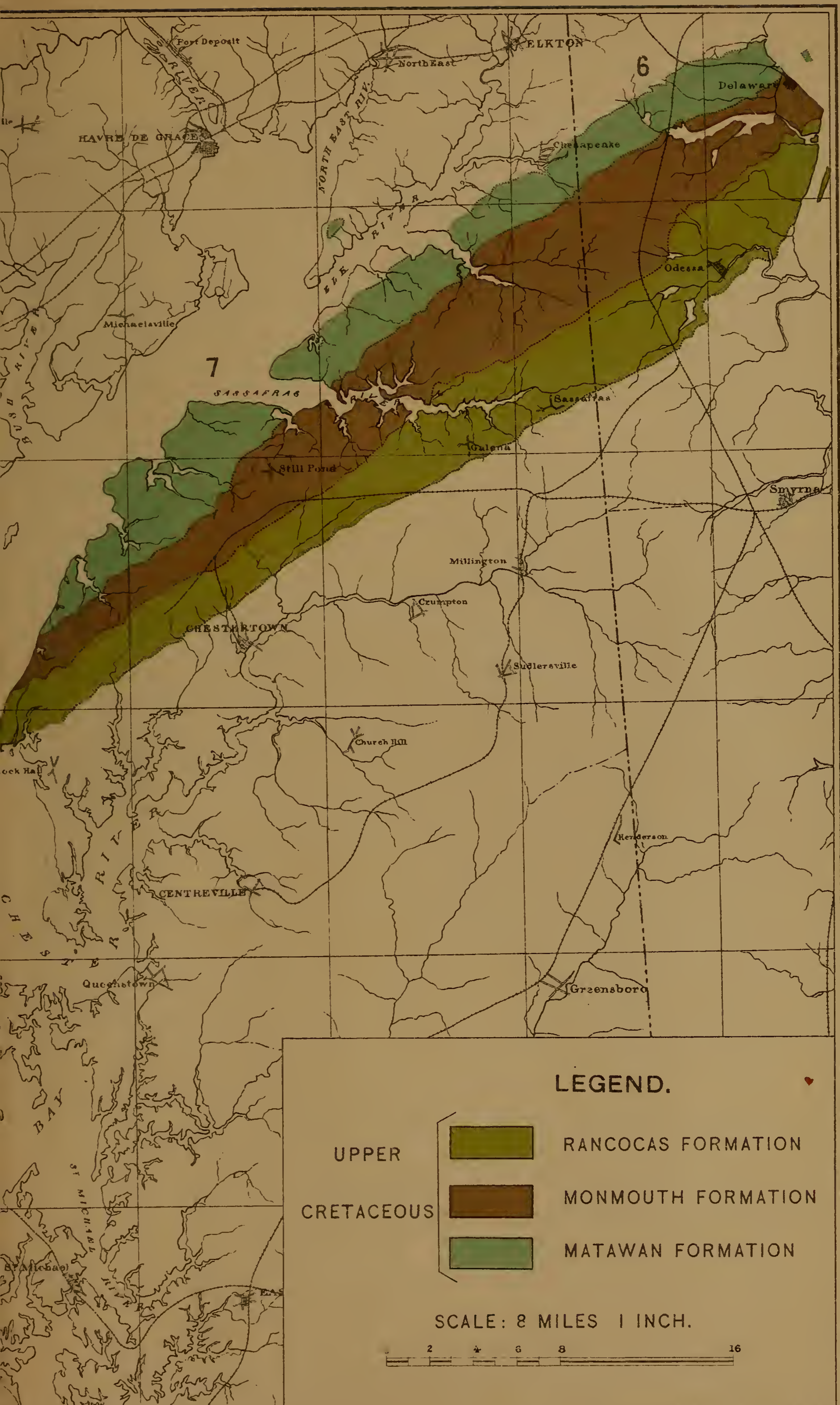
Stratigraphic relations.—The Matawan formation rests unconformably upon Lower Cretaceous strata throughout the northern Atlantic Coastal plain. Locally the line is at times not readily discernible, especially when the upper portion of the Lower Cretaceous contains beds of dark colored clay, such as characterize the strata to some extent in the northern portion of the region. Commonly, however, the line of contact is sharply defined, since the upper portion of the Lower Cretaceous consists generally of white sands or fine gravel, which can be readily distinguished from the overlying Matawan. Not infrequently, however, in the interstream portions of the country, the line of contact is obscured by late Tertiary or Quaternary deposits, so that its location has to be hypothetically determined for cartographic purposes, unless well-borings can be found or the beds reached by the geologist's auger.

The Matawan formation is conformably overlain by the succeeding formation, but the lithologic differences are so clearly marked throughout the whole area of occurrence of the two formations that the line of contact can be readily determined.

Divisions—General characteristics.—The Matawan formation can be readily subdivided upon lithologic grounds throughout the northern portions of the area, while to the south these differences become gradually obscured, until in the southern portion of New Jersey, in Delaware, and in Maryland the divisions observed in the north can be no longer recognized.

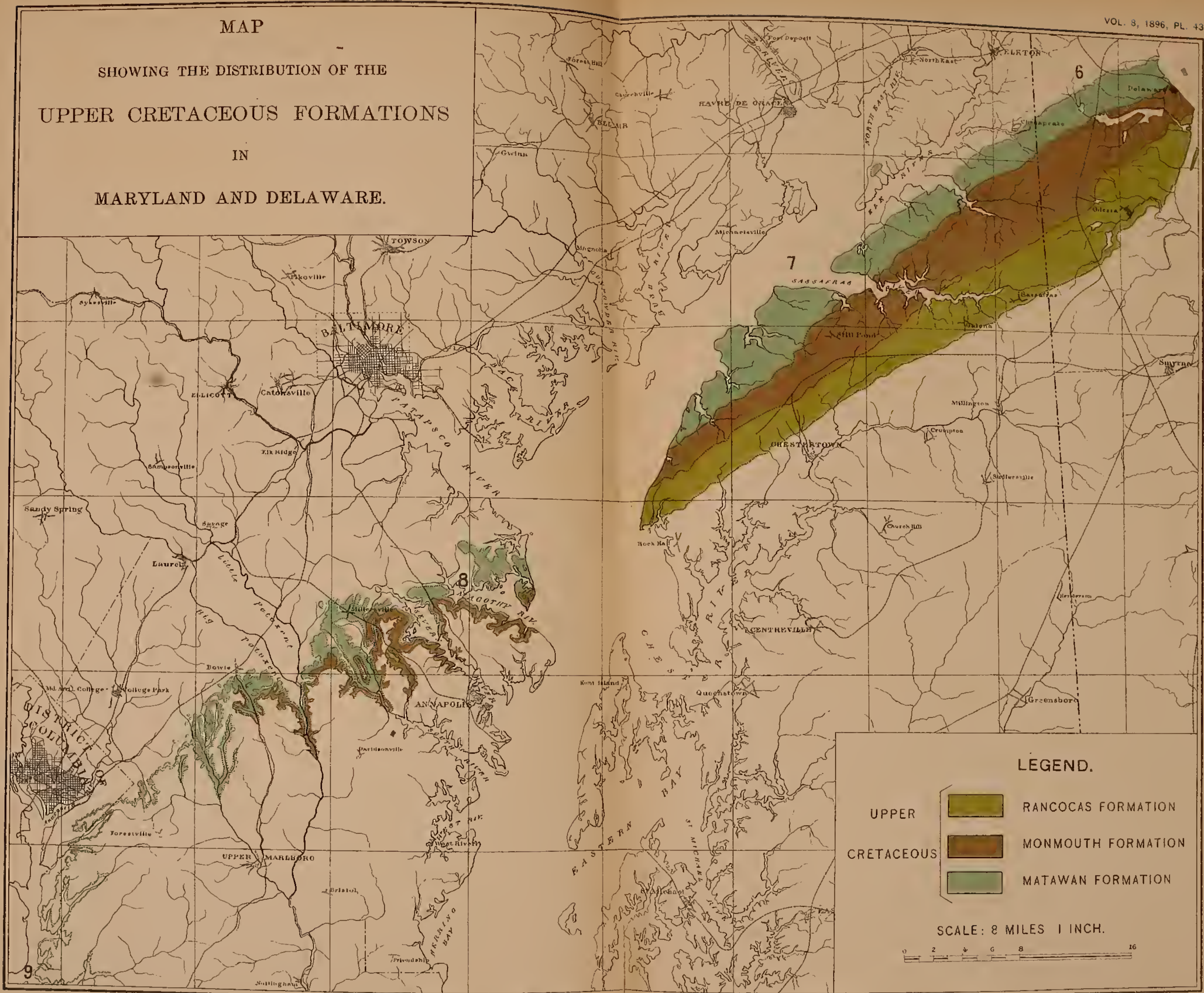
The northern series will be considered under the head of the Crosswicks Clays and the Hazlet Sands, so called from localities where they


MAP
SHOWING THE DISTRIBUTION OF THE
UPPER CRETACEOUS FORMATIONS
IN
MARYLAND AND DELAWARE.
Forest Hill
Gwinn
TOWSON
Magnolia
Pikeville
Sykesville
BALTIMORE
ELLICOTT
Catonsville
PATAPSCO RIVER
BACK RIVER
Elk Ridge
Sampsonville
Sandy Spring
Savage
Laurel
Little Patuxent
Big Patuxent
8
MAGOTHY RIV.
Millersville
SEVERN
Bowie
Md. Agril. College
College Park
ANNAPOLIS
DISTRICT OF COLUMBIA
Forestville
Davidsonville
WEST RIV.
West River
UPPER MARLBORO
Bristol
HERRING BAY
Friendship
Nottingham
9



ORMATIONS IN MARYLAND AND DELAWARE

PHOTO LITH BY A. HOEN & CO. BALTIMORE MD



DISTRIBUTION OF THE UPPER CRETACEOUS FORMATIONS IN MARYLAND AND DELAWARE

typically occur, the first obtaining its name from the village of Crosswicks, upon Crosswicks creek, Burlington county, where the clays are well developed and extensively worked, and the second from the town of Hazlet, in Monmouth county, situated in the center of the sands, which are well developed in the surrounding territory.

Crosswicks clays.—These clays constitute the lower portion of the Matawan formation in Monmouth, Middlesex, Mercer, Burlington, and Camden counties. This lower division consists primarily of very dark colored or black clays, which become at times slate or drab colored toward the top, or, as in the vicinity of Matawan creek, interstratified with layers of white sand. The dark clays are frequently quite glauconitic, but the glauconite is confined generally to thin seams and pockets. This marly feature becomes less pronounced toward the upper portion of the series and often entirely disappears. These clays, particularly in the lower part, are quite unctuous when wet, but become more and more brittle toward the top, while there is also a marked decrease in the amount of iron sulphide. The Crosswicks clays are well exposed upon the shores of Raritan bay and in the valleys of Matchaponix creek, Crosswicks creek, Black creek, and other streams entering the Delaware river. Toward the south the Crosswicks clays gradually become more arenaceous and more micaceous and cannot be readily separated from the overlying deposits.

Hazlet sands.—These sands comprise the upper portion of the Matawan formation throughout the same area as the Crosswicks clays. This upper division consists primarily of sands, highly ferruginous and brown in color in the lower portions and often affording indurated crusts. Above this brown sand there is frequently found a well developed dark colored clay, which is very much like the lower Crosswicks clays in many of its characteristics, although oftentimes partaking to a considerable extent of the micaceous features of the overlying sands. These upper sands, generally very micaceous and at times quite dark in color, are very persistent at the top of the Matawan formation throughout the northern portion of the district. They become more argillaceous and darker in color to the southward and lose to a considerable extent their characteristic features.

Toward the south the division of the Matawan into Crosswicks clays and Hazlet sands becomes gradually obscured as the lower member becomes more and more arenaceous and micaceous, while the upper member becomes more and more argillaceous, until finally in Gloucester and Salem counties, New Jersey, the materials are practically identical and consist of dark colored arenaceous clays, generally glauconitic and micaceous. These features continue upon the south bank of the Delaware river in the state of Delaware and throughout Maryland, but the glauconitic element gradually becomes reduced to the southward and the clays become finer and more micaceous.

Fossils.—The fossils of the Matawan formation, although not so numerous or well preserved as in some of the other members of the Cretaceous series, afford a large number of different species which have been obtained with sufficient frequency to establish beyond all doubt the stratigraphic limits and areal distribution of the formation throughout its entire extent from northern New Jersey to southern Maryland. Many of the species range upward into the overlying formation, while others are limited to the Matawan itself. Among the characteristic and common species found in the formation and determined by the authors are the following:

Rhabdogonium tricarinatum, var. *acutangulum*, Reuss.
Frondicularia pulchella, Karrer.
Hemiaster parastatus, Morton.
Terebratella plicata, Say.

Ostrea larva, Lamarck.
Exogyra costata, Say.
Gryphæa vesicularis, Lamarck.
Anomia tellinoides, Morton.
Amusium conradi, Whit.
Camptonectes burlingtonensis, Gabb.
Neithea quinquecostata, Sowerby.
Spondylus gregalis, Morton.
Plicatula urticosa, Morton.
Dianchora echinata, Morton.
Gervilliopsis ensiformis, Conrad.
Inoceramus sagensis, Owen.
Pinna laqueata, Conrad.
Arca quindecemradiata, Gabb.
Idonearca antrosa, Morton.
Idonearca vulgaris, Morton.
Axinea mortoni, Conrad.
Nucula slackiana, Gabb.
Trigonia mortoni, Whit.
Crassatella vadosa, Morton.
Crassatella delawarensis, Gabb.
Lucina smockana, Whit.
Cardium dumosum, Conrad.
Cardium tenuistriatum, Whit.
Cardium perelongatum, Whit.
Cardium multiradium, Gabb.
Leiopistha protexta, Conrad.
Cymella meeki, Whit.
Veniella conradi, Morton.
Veniella subovalis, Conrad.
Callista delawarensis, Gabb.
Aphrodina tippana, Conrad.
Cyprimeria densata, Conrad.
Tenea pinguis, Conrad.
Tellimera eborea, Conrad.
Linearia metastriata, Conrad.
Veleda lintea, Conrad.
Pholadomya occidentalis, Morton.
Panopaea decisa, Conrad.
Clavagella armata, Morton.

Pyropsis naticoides, Whitfield.
Pyropsis reileyi, Whit.
Pyrifusus cuneus, Whit.
Odontofusus slacki, Gabb.
Odontofusus typicalis, Whit.
Volutomorpha conradi, Gabb.
Turbinella (?) *verticallis*, Whit.
Voluta (?) *delawarensis*, Gabb.
Volutoderma abotti, Gabb.
Lunatia halli, Gabb.
Gyrodes altispira, Gabb.
Gyrodes obtusivola, Gabb.
Gyrodes infracarinata, Gabb.
Gyrodes petrosa, Morton.
Margarita abyssina, Gabb.
Xenophora leprosa, Morton.
Endoptygma umbilicata, Toumey.
Scalaria thomasi, Gabb.

Volutoderma woolmani, Whit.
Rostellites nasutus, Gabb.
Rostellites angulatus, Whit.
Rostellites texturatus, Whit.
Cithera crosswickensis, Whit.
Alaria rostrata, Gabb.
Anchura abrupta, Morton.
Anchura compressa, Whit.
Natica abyssina, Morton.
Scalaria sillimani, Morton.
Turritella encrinoides, Morton.
Turritella vertebroides, Morton.
Turritella pumila, Gabb.
Turritella lippincotti, Whit.
Modulus lapidosa, Whit.
Avellana bullata, Morton.
Dentatium subarcuatum, Conrad.
Dentalium falcatum, Conrad.

Ammonites (*Placenticeras*) *placenta*, De Kay.
Ammonites delawarensis, Morton.
Ammonites vanuxemi, Morton.
Scaphites hippocrepis, De Kay.
Scaphites nodosus, Owen.
Baculites ovatus, Say.

MONMOUTH FORMATION.

Name.—The Monmouth formation receives its name from the county of Monmouth, in New Jersey, throughout which the deposits of this horizon are most characteristically developed. A more local reason for its use is found in the fact that the famous revolutionary "Monmouth Battle Ground" is situated upon this formation. The name is now proposed, for the first time, to embrace the Navesink and Redbank formations* of previous contributions, and to include. as well, certain sands which underlie them, but which are so insignificantly developed in the northern portion of New Jersey as not to have been regarded of special significance at the time these formations were established and characterized. This increase in the limits of the formation has been rendered necessary by the discovery throughout the southern portions of the region now under consideration of conditions which render the differentiation of the several members quite impossible. This division of the series still holds good for the northern counties, but as a classification is sought which may be strictly applicable to the entire northern Atlantic Coastal plain, a revision becomes necessary, the older terms being retained to designate the subdivisions wherever they occur.

Areal distribution.—The Monmouth formation occupies the country to the east of the Matawan formation and extends as a narrow belt from Raritan bay to the valley of the Patuxent river, in southern Maryland, beyond which it does not appear in association with the Matawan formation except at a single doubtful locality in the valley of the Potomac river near Fort Foote. In northern New Jersey the outcrop of the main body of the formation increases rather rapidly from a maximum width of nearly eight miles in the vicinity of the Mount Pleasant hills to barely three miles at Freehold, and with the exception of marked local increases in width

* Journal of Geology, vol. ii, pp. 164-166, 1894.

when the face of the escarpment juts far out to the westward, continues to hold this width for the most part throughout southern New Jersey. The belt of outcrop is, however, very irregular and along some of the deeper valley lines crossing the escarpment does not exceed a mile in width. In Delaware and upon the eastern shore of Maryland the belt again broadens and in the valley of the Sassafras river reaches five miles in width. Upon the western shore of Maryland it is much narrower and gradually tapers down until it entirely disappears just beyond the border of Prince Georges county, with the possible exception of a single occurrence near Fort Foote, on the Potomac river.

Character of materials.—The deposits of the Monmouth formation are variable, but sands largely predominate. As different types of materials to a large extent characterize the subdivisions, a more accurate description will be given of them in that connection. In general the sands are highly ferruginous and to a large extent glauconitic, becoming also at times very argillaceous toward the south. The sand deposits are frequently indurated either by iron or by carbonate of lime, the latter being furnished by the fossil shells which at times crowd the beds.

Strike, dip, thickness.—The strike and dip of the Monmouth formation are essentially the same as in the case of the Matawan formation, but can be somewhat more readily determined on account of the topographic situation of the strata.

The thickness of the deposits is less variable than in the case of the Matawan formation, but gradually declines from about 150 feet in northern New Jersey to 60 feet to the east of Philadelphia, beyond which point it continues to increase, reaching somewhat over 60 feet in Gloucester county and about 85 feet in Salem county. In Delaware it is about 60 feet, and on the eastern shore of Maryland it increases in the region of the Sassafras river to 85 feet. Upon the western shore of the Chesapeake bay, in the valleys of the Magothy and Severn rivers in Anne Arundel county, its thickness is again reduced to 50 feet, beyond which it rapidly declines, until in the valley of the Patuxent it is only 10 feet, and shortly thereafter entirely disappears.

Stratigraphic relations.—The Monmouth formation lies conformably upon the Matawan formation throughout the area observed. The division line is generally sharply defined where the basal red sands come in contact with the micaceous sands and the sandy marls of the Matawan.

The relations between the Monmouth formation and the overlying Rancocas formation are not so clear on account of the very great difference in the upper members of the Monmouth formation itself in the different portions of its area of outcrop, the Rancocas formation resting throughout a portion of the region upon red sands, while elsewhere it lies upon

SASSAFRAS RIVER, MARYLAND, BELOW CASSIDYS LANDING

Showing Matawan clays at base and Monmouth formation above.

micaceous sandy clays. This may find its explanation in either one of two ways. It may be the result of actual unconformity or it may be brought about by the change of the sandy members of the upper Monmouth in northern New Jersey, until they gradually become replaced by clays toward the south, to be succeeded by sands upon the eastern shore of Maryland, where the formation again thickens. The structural relations are not sufficiently clearly defined to absolutely determine this point, although there are strong indications in certain places, shown in the marked change in the general aspect of the materials and the sharp lines of contact, to indicate that unconformity exists. In that case it is not impossible that the sands of the upper Monmouth have suffered removal through central and southern New Jersey, although this would not be necessary, since both the thinning out of the sands and gradual replacement by clays, as well as unconformity, could occur, and the explanation of the relations observed may be found in a combination of the two hypotheses. The unconformity, if it exists, doubtless represents a very brief interval, since the general conditions did not largely change, while the life forms of the previous age persisted in a number of instances into the later period. Although most careful and detailed observations and measurements have been made in the area where the sands finally disappear, there is still some question as to the presence of unconformity; yet it may safely be assumed as a tentative hypothesis, with the reservation that it may wholly or in part be accounted for by the marked change in the character of sedimentation.

Divisions—General characteristics.—The Monmouth formation can be subdivided upon lithologic grounds throughout a large part of its area into three members, which are especially well marked in the northern portion of the district and upon the eastern shore of Maryland, but are less clearly defined in central and southern New Jersey and upon the western shore of Maryland. The three divisions in ascending order are the Mount Laurel sands, the Navesink marls, and the Redbank sands. The latter two have been previously named from typical areas in Monmouth county, while the first receives its designation from mount Laurel, situated to the east of Camden, in Burlington county, where the sands of this horizon are most extensively developed.

Mount Laurel sands.—These sands are, on the whole, perhaps the most constant member of the Monmouth formation, although very variable in thickness and changing considerably in their character as they extend southward into Maryland. They consist typically of coarse red sands that are often indurated on account of the large amount of iron present in them. They are more or less glauconitic, especially toward the south, and in their more unweathered portions, when reached by well-borings, are frequently grayish or light greenish gray in color. They have a thickness of about five feet in the vicinity of Atlantic highlands, which slowly increases to the southward, until in the region to the east of Philadelphia they have increased to over 25 feet. Beyond that point they increase more rapidly throughout the southern counties, reaching 50 feet in Gloucester county and fully 80 feet in the vicinity of Salem. In Delaware and in the eastern counties of Maryland they are between 30 and 40 feet, but on the western shore of the Chesapeake they cannot be sufficiently well differentiated to be separated from the overlying members. They have often been confused with the Redbank sands, which overlie the marls.

Navesink marls.—These marls, embracing the Lower Marl bed of Cook, extend with a remarkably constant thickness of from 40 to 50 feet from the Highlands of Navesink throughout Monmouth and northern Burlington counties, beyond which they cannot be very well differentiated from the overlying Redbank sands until eastern Maryland is reached, where the two members reappear, although the marls are of very much less thickness, generally not exceeding 12 feet. The Navesink marls are typically glauconitic sands which themselves admit of further subdivision throughout much of Monmouth county. The basal portion consists generally of arenaceous beds that have been hitherto referred to under the name of sand marl and which are generally highly fossiliferous wherever found. A great variety of fossil species has been obtained from this horizon. Above the sand marl, in the northern portion of the area, is a very compact blue marl which is highly glauconitic and frequently fossiliferous in its central portions, a firm shelly layer at times resulting (plate 46). The upper portion of the Navesink marls is commonly more micaceous, and just at the top is at times quite sandy. Farther to the south, in central and southern New Jersey and in Delaware, the Navesink marls become much more argillaceous, the glauconite being much reduced in amount. Whether the argillaceous marls throughout this district represent the Navesink marls alone, or a part or all of the Redbank sands as well, cannot be altogether satisfactorily determined. If unconformity exists, as seems probable, it is even possible that these argillaceous marls may not in all cases even represent the full development of the Navesink in the north. The changes which have taken place in the materials makes it difficult to say just how much of the middle and upper Monmouth should be included.

Redbank sands.—These sands, comprising the Red sand of Cook, are most typically developed in the region about Redbank, Monmouth county, and in the highlands forming the Cretaceous escarpment in the region to the north and west of that town. Throughout most of Monmouth county the Redbank sands have a thickness of about 100 feet, which declines gradually to the southward until in the Pine Hill region it has dropped to about 60 feet, from which point it still further declines to the region of Red hill, in Burlington county, beyond which it entirely disappears unless replaced by the argillaceous deposits which have been above described.

The Redbank sands, as developed in the north, do not occur throughout southern New Jersey, but reappear in Delaware and the eastern counties of Maryland, where their characteristic features are again developed and where they have a thickness in the Sassafras river basin of about 60 feet. They decline somewhat in thickness toward the Chesapeake bay, and upon the western shore of the Chesapeake cannot be distinguished from the other members of the Monmouth formation. The deposits, in the two areas where all the members are characteristically developed, consist typically of very red sands which in their more unweathered portions carry grains of glauconite. Beds of dark sandy marl and black micaceous clay are at times interbedded with the sands, the former frequently occurring at the base while the latter is more common higher in the series. A greenish gray or reddish clay, more or less indurated, occurs at the very top of the formation in Monmouth county and forms a firm unyielding capping for the Monmouth formation (plate 47).

Fossils.—The fossils of the Monmouth formation are very numerous and well preserved, at times forming solid shelly layers. Many of the species are identical with those found in the Matawan formation, while a few are found ranging upward into the Rancocas formation. A considerable number of forms are restricted, however, to the Monmouth itself. Among the characteristic and common species found in this formation and determined by the authors are the following:

Bolivina punctata, D'Orbigny.
Marginulina trilobata, D'Orbigny.
Vaginulina strigillata, Reuss.
Cristellaria cultrata, Montfort.

Ostrea larva, Lamarck.
Ostrea tecticosta, Gabb.
Ostrea crenulimarginata, Gabb.
Gryphea convexa, Morton.
Gryphea vesicularis, Lamarck.
Exogyra costata, Say.
Anomia argentaria, Morton.
Camptonectes parvus, Whit.
Neithea quinquecostata, Sowerby.
Spondylus gregalis, Morton.
Plicatula urticosa, Morton.

Catopygus pusillus, Clark.
Cassidulus florealis, Morton.
Terebratella vanuxemi, Lyell and Forbes.

Axinea mortoni, Conrad.
Nuculana protexta, Gabb.
Trigonia mortoni, Whit.
Trigonia cerulea, Whit.
Crassatella vadosa, Morton.
Crassatella subplana, Conrad.
Diceras dactyloides, Whit.
Cardium eufaulensis, Conrad.
Cardium dumosum, Conrad.
Cardium multiradiatum, Whit.
Leiopistha protexta, Conrad.

Radula pelagica, Morton.
Lithodomus ripleyana, Gabb.
Trigonarca transversa, Gabb.
Cibota rostellata, Morton.
Cibota multiradiata, Gabb.
Idonearca antrosa, Morton.
Idonearca vulgaris, Morton.
Axinea alta, Whit.
Veniella conradi, Morton.
Callista delawarensis, Gabb.
Aphrodina tippana, Conrad.
Cyprimeria excavata, Morton.
Periplomya elliptica, Gabb.
Panopæa decisa, Conrad.
Legumen planulatum, Conrad.
Clavagella armata, Morton.

Pyropsis retifer, Gabb.
Pyropsis richardsoni, Tuomey.
Pyropsis obesa, Whit.
Pyropsis septemlirata, Gabb.
Pyrifusus cuneus, Whit.
Neptunella mullicaensis, Whit.
Odontofusus typicus, Whit.
Odontofusus medians, Whit.
Volutomorpha conradi, Gabb.
Volutomorpha ponderosa, Whit.
Vasum conoides, Whit.
Rostellites nasutus, Gabb.
Volutoderma ovata, Whit.
Turbinopsis hilgardi, Conrad.
Turbinopsis curta, Whit.
Cithara mullicaensis, Whit.
Rostellites compacta, Whit.
Rostellaria spirata, Whit.
Rostellaria hebe, Whit.
Anchura compressa, Whit.
Gyrodes abbotti, Gabb.
Gyrodes infracarinata, Gabb.
Gyrodes altispira, Gabb.
Lunatia halli, Gabb.
Amauropsis punctata, Gabb.
Margarita abyssina, Gabb.
Margaritella abbotti, Gabb.
Xenophora leprosa, Morton.
Turritella encrinoides, Morton.
Turritella vertebroides, Morton.
Turritella lippincotti, Whit.
Actæon forbesiana, Whit.
Cinulia naticoides, Gabb.
Dentalium subarcuatum, Conrad.

Nautilus dekayi, Morton.
Baculites ovatus, Morton.
Belemnitella americana, Morton.

RANCOCAS FORMATION.

Name.—The Rancocas formation previously named * and characterized, is so called from its typical development in the valley of Rancocas creek in Burlington county, New Jersey. It comprises in general terms the Middle Marl bed of Professor Cook, although portions of that author's Yellow Sand may be here included, while other portions may fall within the next higher division, although it seems more probable, however, that certain yellowish sands in eastern Monmouth county, derived in part from the underlying greensand marls, but of Miocene age, were regarded as part of the Upper Cretaceous, so that the Yellow Sand is not to be sought for in the Cretaceous at all, and need not be further considered.

Areal distribution.—The Rancocas formation occupies the country to the east of the Monmouth formation, and extends from Raritan bay to the valley of Severn river in Maryland, where its last outcrop occurs. In northern New Jersey the width of outcrop of the main body of the formation to the south of the escarpment is generally between three

* Journal of Geology, vol. ii, p. 166, 1894.

VERTICAL SECTIONS OF UPPER CRETACEOUS FORMATIONS IN NEW JERSEY AND MARYLAND.

and four miles, but this width is considerably increased by the exposures which are made by the easterly flowing streams, but more especially by the outliers which are found upon the higher points of the escarpment. Its areal distribution decreases in width in central Monmouth county to some extent on account of the topographic configuration of the country, but in central and southern New Jersey, on account of the greater thickness of the deposits, considerably expands, until in Camden and Gloucester counties it reaches a width of five or six miles. Toward the south, in Salem county, it again somewhat contracts. In Delaware and the eastern counties of Maryland, on account of the extremely level character of the country, its area of outcrop is increased, but it narrows southward toward the shore of Chesapeake bay, and is only represented in a few isolated remnants on the western side, and entirely disappears on the north bank of Severn river.

Character of materials.—The deposits of the Rancocas formation consist for the most part of greensand marls, at times very highly calcareous, especially in central and southern New Jersey. Some of the beds are crowded with fossils, so that shelly bands occur which are often locally indurated. The greensand marls frequently become highly argillaceous, producing a chocolate colored marl.

Strike, dip, thickness.—The strike and dip of the deposits of the Rancocas formation conform more or less closely to those of the preceding members of the upper Cretaceous, and can be quite readily determined on account of the topographic relations of the strata. The dip, obtained by connecting the beds upon the crest of the escarpment with the main body of the deposits to the eastward, is shown to be on the average about 25 feet in the mile.

The thickness of the deposits is fairly constant throughout the northern portion of the area to the north of Rancocas creek, and has been estimated to be between 45 and 50 feet. To the south of this region it slightly increases in thickness through Camden and Gloucester counties, and then suddenly expands in Salem county, where it attains a maximum thickness of 125 feet. To the south of the Delaware river, on the Delaware peninsula, it declines rapidly in thickness, and at the Maryland state line has again become reduced to about 50 feet. Near the shore of Chesapeake bay it has still further declined to 30 feet, while upon the western shore of the bay, in eastern Anne Arundel county, the deposits are only a few feet in thickness at the isolated points observed.

Stratigraphic relations.—The relations between the Rancocas formation and the underlying Monmouth formation have already been described. The materials of the Rancocas formation are very distinct from the beds beneath and give indication, both upon this and other grounds, as has been above shown, of unconformity, although this has not been absolutely proven.

The Rancocas formation is overlain conformably by the Manasquan formation, although but few points of contact have been observed on account of the very general overlapping of the Miocene deposits throughout this area. The best exposures are seen in the valley of Manasquan river, near Freehold, and on the southwest branch of Rancocas creek, in the vicinity of Medford, where the lime-sands of the Rancocas formation are overlain by the light colored clay at the base of the Manasquan.

Divisions—General characteristics.—The Rancocas formation throughout New Jersey admits of subdivision, upon both lithologic and paleontologic grounds, into two members, but beyond the Delaware river in Delaware and Maryland the distinctions, so clearly marked in the north, are gradually lost. The two divisions in New Jersey are, in ascending order, the Sewell marls, so named from Sewell, in Gloucester county, and the Vincentown lime-sands, so called from Vincentown, in Burlington county, in both of which localities the deposits are characteristically developed.

Sewell marls.—These marls form a very constant horizon that can be readily traced the entire distance across the state of New Jersey. They consist typically of dark greensand marls, throughout which the glauconite is thickly disseminated, although this substance diminishes in amount in passing southward. The Sewell marls have a thickness of about 30 feet in northern New Jersey, but become somewhat reduced in amount in the southern counties, declining to less than 20 feet in Salem county.

The Sewell marls are characterized by a highly fossiliferous band near the top, although casts of molluscan shells and the bones of saurians are found throughout this division. The fossiliferous zone at the top is often packed with shells, the lower portion of it being made up almost exclusively of the shells of *Gryphæa vesicularis*, while the upper part is often composed of the shells of *Terebratula harlani*. These fossil layers are remarkably persistent, extending as an almost continuous band across the state.

Vincentown lime-sands.—These lime-sands are well developed throughout the central and southern counties of New Jersey, and consist of highly calcareous greensands, the calcareous element being supplied by the vast number of Bryozoan shells which crowd the beds. At times the beds are almost purely calcareous, and at many points, especially near the top of the Rancocas formation, become consolidated into firm, limestone ridges. The Vincentown lime-sands have a constant thickness of about 20 feet in northern and central New Jersey, but increase gradually to the southward and in Salem county suddenly expand until they attain a thickness of about 100 feet.

MONMOUTH FORMATION ON CRASSWICKS CREEK, NEW JERSEY

Showing Mount Laurel sands and Navesink marls. View taken at a point three miles below New Egypt.

DEEP CUT SOUTH OF KEEPORT, NEW JERSEY

Showing Redbank sands of Monmouth formation overlain by Rancocas formation.

To the south of New Jersey, in Delaware and Maryland, this subdivision of the Rancocas into two members becomes gradually obscured, although the lime-sands still continue to characterize to some extent the upper portions of the formation on the eastern side of the Chesapeake, but at the same time the *Terebratula harlani* is no longer limited to its former horizon at the top of the Sewell marls, but occurs frequently within and even at the top of the lime-sands. The lower member also changes its character, becoming less glauconitic and grayish or reddish gray in color.

Fossils.—The fossils of the Rancocas formation are less varied in species, but very numerous in individuals, and at times largely make up the strata, as above described. A few of the species are identical with those found at lower horizons, while a few continue on into the succeeding Manasquan formation, but the majority have not yet been found elsewhere. Among the characteristic and common species found in this formation, and with one or two exceptions obtained and determined by the authors, are the following:

Verneuilina triquetra, Munst.
Lingulina carinata, d'Orb.
Flabellina sagittaria (Lea).
Polymorphina communis, d'Orb.

Pentacrinus bryani, Gabb.
Goniaster mammillata, Gabb.
Cidaris splendens, Morton.
Cidaris walcotti, Clark.
Salenia tumidula, Clark.
Salenia bellula, Clark.
Pseudodiadema diatretum, Morton.
Coptosoma speciosum, Clark.
Trematopygus crucifer, Morton.
Catopygus oviformis, Conrad.
Ananchytes ovalis, Clark.
Cardiaster cinctus, Morton.
Hemiaster parastatus, Morton.
Hemiaster stella, Morton.
Hemiaster ungula, Morton.

Terebratula harlani, Morton.
Terebratula harlani, var. *fragilis*, Morton.
Cistella beecheri, Clark.

Gryphæa vesicularis, Lamarck.
Gryphæa bryani, var. *precedens*, Whit.
Gryphæostrea vomer, Morton.
Idonearca medians, Whit.
Teredo tibialis, Morton.
Gastrochæna americana, Gabb.

Perissolax trivolva, Gabb.
Cavoscula annulata, Morton.
Pleurotrema solariformis, Whit.

Nautilus bryani, Gabb.
Nautilus dekayi, Morton.
Ammonites (*Sphenodiscus*) *lenticularis*, Owen.

MANASQUAN FORMATION.

Name.—The Manasquan formation * receives its name from the Manasquan river, in Monmouth county, New Jersey, where the most complete

* Journal of Geology, vol. ii, 1894, pp. 166, 167.

section of the deposits of this horizon is found. If the Yellow Sand described by Professor Cook really constitutes a part of the Cretaceous series, then a part of it should be referred to the basal portion of the Manasquan formation. As above explained, it is highly probable that the Yellow Sand, as described by Professor Cook, is really of Miocene age, and does not belong to the Upper Cretaceous series at all. The Manasquan formation embraces the lower and middle members of the Upper Marl bed of Professor Cook, including what was described under the name of the Green marl and the Ash marl of that division.

Areal distribution.—The Manasquan formation is confined exclusively to the northern portion of the New Jersey area, extending from the region just south of Long Branch, in Monmouth county, across the northern portion of Ocean county into Burlington county, but entirely disappearing a short distance beyond its border in Camden county. The width of outcrop of the formation is very variable, on account of the encroachment of the Miocene deposits, which very frequently entirely bury the strata of the Manasquan from view, thus temporarily interrupting its continuity. Where the Miocene deposits have been stripped off by streams, as along the line of the Manasquan river and its tributaries, it may attain a width of 3 or 4 miles, but more often the width does not exceed 1 or 2 miles, with frequent variations, as above cited.

Character of materials.—The deposits of the Manasquan formation consist typically of highly glauconitic greensands of a deep green color. They may at times, by the admixture of argillaceous materials, have a somewhat ashy color, which is characteristic of the beds to which Professor Cook gave the name of "Ash marl." This ash-colored marl is not always confined to the upper portion of the Manasquan formation, however, but more often found there. At the base of the Manasquan formation there is often a layer of fine clay, very light in color, which is commonly referred to under the name of "fullers earth."

Strike, dip, thickness.—The strike and dip of the Manasquan formation conform in general to the strike and dip of the preceding members of the Upper Cretaceous series, so far as can be determined by a study of the sections and of the well-borings. The topographic relations of the strata are such as to preclude satisfactory measurements, such as were possible in the case of the Rancocas and Monmouth formations.

The thickness of the formation diminishes gradually from very nearly 50 feet in the northern portion of its area of occurrence to about 40 feet at the eastern border of Burlington county, beyond which it more rapidly declines, reaching 30 feet in the southwestern portion of the county, and entirely disappearing by the overlapping of the Miocene shortly thereafter.

Stratigraphic relations.—The Manasquan formation rests conformably upon the Rancocas formation, the line of contact being sharply defined in the few places where surface exposures have been found. At these points, namely, upon the Manasquan river to the west of Farmingdale and upon the southwest branch of Rancocas creek to the southwest of Medford, the light-colored clays which form the base of the Manasquan rest conformably upon the Vincentown lime-sands of the Rancocas formation. The Manasquan formation is conformably overlain by the succeeding Shark River formation, the line being less sharply defined than in the case of the basal contact.

Fossils.—The fossils of the Manasquan formation are neither numerous in individuals nor in species, except at a few localities. The forms determined are the following:

Textularia agglutinans, d'Orbigny.
Tritaxia tricarinata (Reuss).
Nodosaria spinulosa (Montagu).
Globigerina bulloides, d'Orbigny.
Truncatulina wuellerstorfi (Schwager).
Terebratulina atlantica, Morton.

Ostrea glandiformis, Whitfield.
Gryphæa bryani, Gabb.
Modiola johnsoni, Whit.
Arca quindecemradiata, Gabb.
Cardita intermedia, Whit.
Crassatella conradi, Whit.
Crassatella delawarensis, Gabb.
Crassatella littoralis, Conrad.
Crassatella rhombea, Whit.
Cardium (*Criocardium*) *nucleolus*, Whit.
Veniella rhomboidea, Conrad.
Caryatis (?) *veta*, Whit.
Petricola nova-ægyptica, Whit.
Veleda nasuta, Whit.
Periplomya truncata, Whit.
Panopæa elliptica, Whit.

SHARK RIVER FORMATION.

Name.—The Shark River formation* was earlier so named from its typical occurrence in the upper valley of Shark river, Monmouth county, New Jersey. It includes the upper division of the Upper Marl bed which was designated as Blue marl by Professor Cook.

Areal distribution.—The Shark River formation is confined to a very limited district in eastern Monmouth county, New Jersey, being known definitely only to the northwest of Asbury Park and in the valleys of the Shark and Manasquan rivers. Its surface outcrops are confined to the valley sides, being deeply buried in the intervening country by Miocene deposits. To the south of Monmouth county the Shark River formation has been nowhere observed, although it doubtless occurs beneath the Miocene cover.

Character of materials.—The deposits of the Shark River formation consist of very fine dark green sands, at times with a bluish tinge, and with a greater or less admixture of argillaceous materials. An indurated stony

* Journal of Geology, vol. ii, 1894, p. 167.

layer is commonly found at the top of the formation in the limited area where it has been observed.

Strike, dip, thickness.—The strike and dip of the Shark River formation are similar to those of the preceding formations, so far as is revealed from the few surface exposures and the records obtained from well-borings.

The thickness of the beds is between 10 and 15 feet, and at points exposed in the Shark River and Manasquan valleys is estimated as pretty constant at about 12 feet. As the Shark River formation has only been observed upon its beveled edges near its contact with the Manasquan formation, it is highly probable that it increases considerably in thickness to the southeastward beneath the Miocene cover.

Stratigraphic relations.—The Shark River formation rests conformably upon the underlying Manasquan formation, and its deposits are not separated by any sharply defined lithologic distinction, although the general character of its materials is somewhat different from that of the underlying strata. The Shark River formation is unconformably overlain by the Miocene deposits, and the line of contact is always clearly marked. The Miocene deposits have a considerably smaller angle of dip than the Shark River beds, as shown by the general overlapping of the former upon the subjacent members of the Cretaceous series.

Fossils.—The fossils of the Shark River formation have much interest, since they are supposed to represent a fauna of a later geological period than that to which the previous formations are referred. Among the characteristic and prominent species are the following:

Ostrea glauconoides, Whitfield.
Gryphæa vesicularis, Lamarck.
Pecten kneiskerni, Conrad.
Nucula circe, Whit.
Nuculana albaria, Conrad.
Axinea conradi, Whit.
Astarta castanella, Whit.
Cardita perantiqua, Conrad.
Protocardium curtum, Conrad.
Veleda equilatera, Whit.
Corbula (Neæra) nasutoides, Whit.

Fusus angularis, Whitfield.
Fasciolaria hercules, Whit.
Caricella ponderosa, Whit.
Voluta lelia, Whit.
Voluta perelevata, Whit.
Voluta (Scaphella) newcomniana, Whit.
Volutilithes sayana, Conrad.
Pleurotoma surculitiformis, Whit.
Conus subsauridens, Whit.
Calyptraphorus velatus, Conrad.
Xenophora lapiferens, Whit.
Mesalia elongata, Whit.

Nautilus cookana, Whit.
Aturia vanuxemi, Conrad.

Interpretation of the Sedimentary Record.

GENERAL CHARACTER OF THE DEPOSITS.

The deposits of the upper Cretaceous, as described in the preceding pages, consist of a great variety of materials, among which sands and

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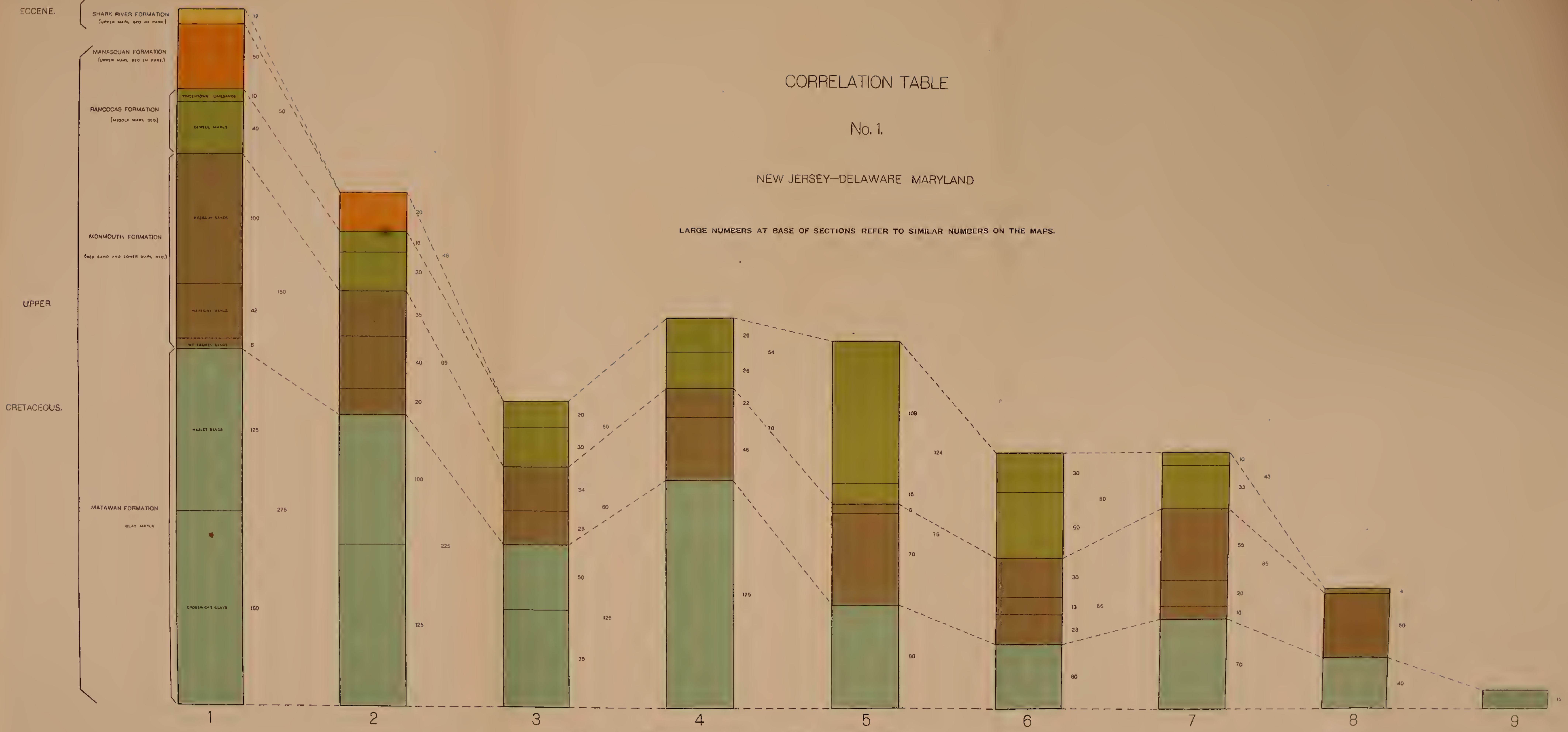
CORRELATION TABLE

No. 1.

NEW JERSEY—DELAWARE MARYLAND

LARGE NUMBERS AT BASE OF SECTIONS REFER TO SIMILAR NUMBERS ON THE MAPS.



CORRELATION OF UPPER CRETACEOUS FORMATIONS IN NEW JERSEY, DELAWARE, AND MARYLAND

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clays are the most conspicuous, although these deposits, as well as the calcareous beds of more local development, contain glauconite in greater or less amounts at nearly every horizon. As the materials, however, differ considerably from one another in general aspect in the several formations, the deposits of each horizon will first be briefly characterized and then contrasted with the other members of the series.

The deposits of the Matawan formation consist chiefly of thick-bedded sands and clays in which the glauconite is for the most part developed in seams and pockets, in this particular standing in marked contrast to all the succeeding members of the upper Cretaceous, where the glauconite is widely, although at times sparingly, disseminated. The clays of the Matawan formation are also much more homogeneous than in any of the succeeding formations, while the unctuous character of the materials is unknown at later horizons. The rapid alternation of finely laminated black clays with white gritty sands, especially well shown in Monmouth county, is very different from anything observed elsewhere in the Upper Cretaceous series.

The deposits of the Monmouth formation consist of a great body of greensand marls and argillaceous beds, more or less highly glauconitic, and situated, where most typically developed, between two horizons of red sands, the latter commonly thick bedded and often indurated in places. The materials of the Monmouth formation are quite distinct from those of the underlying Matawan in their general aspect. The sandy and more glauconitic marls of the Matawan, particularly in the southern part of New Jersey, show some points of resemblance to the more marly members of the Monmouth, but in general the differences are very marked. On the other hand, a comparison of the materials of the Monmouth with those of the overlying formations shows again a clearly defined difference in the character of the beds. The greensand marls of the Monmouth formation are in general less highly glauconitic than the deposits of the higher formations, and can be readily separated both on account of their color and the general composition of the beds. The red sands are quite unknown at later horizons except in certain marginal phases of the Rancocas formation, where even here the weathered glauconite generally retains enough of its character to reveal the true nature of the strata.

The deposits of the Rancocas formation consist for the most part either of highly glauconitic greensands or of calcareous beds in which the glauconite is widely disseminated. The thick bedded greensands, which may at times become chocolate colored by the admixture of argillaceous materials, can be usually readily distinguished from the glauconitic members of the lower formations, although materials more or less closely similar occur in the overlying Manasquan formation. The calcareous beds, on the other hand, are unique, nothing similar being known in any of the other Cretaceous formations. The persistency and great local thickness reached by these beds render this deposit one of, if not the most striking in the entire Cretaceous series of the northern Atlantic Coastal plain.

The Manasquan formation is typically composed of very pure greensands, which in their upper members particularly may become at times ash-colored by an admixture of argillaceous elements. These ashy and drab colored marls are thoroughly characteristic of the Manasquan formation, the more argillaceous members of the lower formations possessing rather a chocolate than an ashy color. The pure greensands too are generally lighter green than the glauconitic deposits of earlier horizons, their nearest allies being seen in the greensands of the Rancocas formation.

The deposits of the Shark River formation are typically bluish colored greensands which become at the top often indurated into stony bands. They are more like the greensands of the Manasquan formation than of any of the preceding formations, but nevertheless possess an individuality of their own.

GEOGRAPHICAL VARIATION IN THE MATERIALS.

Very marked differences are recognized in the materials of the Upper Cretaceous formations in the various parts of the northern Atlantic Coastal plain. With some exceptions the formations are much more fully developed in the north and gradually decline both in thickness and in divisional distinctness toward the south.

The Matawan formation, which has a thickness of fully 275 feet in northern New Jersey, gradually thins southward until it finally disappears in southern Maryland. The divisions also, which are clearly defined in the north, become gradually obscured in central New Jersey, and farther south are not recognized, the materials becoming practically homogeneous throughout. The well marked clays and clearly defined sands of the north gradually give place to micaceous sandy clays and marls that show in a remarkable degree an admixture of the more characteristic substances found in the New Jersey deposits.

The Monmouth formation changes greatly in character between northern New Jersey and central Maryland where it finally disappears. In the north the three divisions previously described are clearly defined, while throughout central and southern New Jersey the upper sandy member is either wanting or replaced wholly or in part by fine argillaceous deposits, the lower sandy member at the same time steadily increasing from the north toward the south until it changes from an insignificant bed to the most important member of the formation. Although the triple division again appears in Delaware and upon the eastern shore of Maryland, it is lost upon the western side of the Chesapeake, where the upper and lower sands with their intervening greensand marls, so well developed in the two areas above described, become merged into pinkish and grayish sands which show no persistent divisions, although possessing more or less variability in their different parts. The highly glauconitic character of the deposits in Monmouth county is gradually lost toward the south, the greensand strata becoming at first more or less argillaceous, while, to the south of the Delaware, both upon the eastern and western sides of the Chesapeake, sands with little glauconite largely predominate, and to the west of the Chesapeake alone represent the formation.

The Rancocas formation is much more highly glauconitic in New Jersey than it is south of the Delaware. The lower greensand member gradually decreases south of Monmouth county, while the upper calcareous member increases in thickness, until in the southern portion of New Jersey it far surpasses the lower greensand division in importance. The great thickness of the calcareous beds in Salem county, New Jersey, is one of the most striking things connected with the geographical variation in the materials of the Upper Cretaceous formations. Although the calcareous member is found to the south of the Delaware, it rapidly declines in thickness upon the Delaware peninsula, beyond which it is not known with certainty to occur, the few feet of Rancocas materials found on the western shore being for the most part greatly weathered, so that their original lithologic characters are much obscured.

The Manasquan and Shark River formations show unimportant geographical variations in their materials. Their area of distribution along the strike, as represented by surface outcrops, is far less in extent than is the case with the other members of the Upper Cretaceous series, and even in their area of occurrence they are largely obscured by the overlying Miocene.

The variations thus far described have had to do entirely with geographical variations along the line of strike as shown either in surface exposures or in well-borings near the margin of the several deposits. Some of the deeper well-borings which have been made to the southeast of the Cretaceous belt, down the dip of the beds, show that in general the various members of the Upper Cretaceous series increase in that direction both in thickness and in the amount of glauconitic materials which they contain. The records of the well-borings, on account of the mixture of materials which is liable to result from the methods pursued, do not always afford an accurate account of the beds penetrated; but, so far as can be judged, the broader formational distinctions which prevail at the surface persist. The records are not altogether satisfactory as regards the subdivisions, however, but it seems highly probable that they change materially and often entirely disappear along the line of dip.

Variations of considerable magnitude in the deposits of the upper Cretaceous of the northern Atlantic Coastal plain are found, as above described, along both the lines of strike and dip, but the chief divisions can everywhere be recognized throughout the area. As they are the only divisions which can be thus employed throughout the region, they have been given formational importance.

PROBABLE MARINE CONDITIONS AS REVEALED BY THE DEPOSITS.

The descriptions of the formations which have been given in the preceding pages show that the upper Cretaceous is chiefly composed of deposits in which glauconite is more or less commonly present. A knowledge of the marine conditions can therefore be gained by instituting a comparison between the deposits of the upper Cretaceous and those in which glauconite is being formed at the present time.

Great light has been thrown upon the origin of greensand deposits as a result of the deep sea dredgings which have been made in recent years by vessels sent out under national auspices. The most important of these expeditions was that of the "Challenger," sent out by the British government in the years 1872–'76. In the report upon the deep sea dredgings published as a result of that expedition Messrs Murray and Renard, the authors, present the latest results upon the character and distribution of greensand, and at the same time propose a theory to account for the chemical changes which have taken place to produce the mineral glauconite which characterizes all greensand deposits.

A typical greensand, such as has been described in most of the Upper Cretaceous formations, is composed of glauconite associated with greater or less amounts of land-derived material, composed of the more common rock-building minerals, together with fragments of the rocks themselves, while to these is commonly added a variable amount of calcareous matter derived from the shells of organisms.

The greensand deposits of the present day are estimated to cover a million square miles of the sea-floor and are found limited to those areas adjacent to the coast, and for the most part along the higher portions of the continental slopes, where land-derived materials are deposited in perceptible, yet small amounts. The "Challenger" dredgings show that the production of glauconite seldom reaches to greater depths than 900 fathoms, and most commonly takes place between 100 and 200 fathoms, although under favorable conditions it may be produced at shallower depths. Its formation is interfered with by the entrance of large rivers bearing sediment into the sea and by the prevalence of strong oceanic currents.

It is a remarkable fact that although greensand is not formed except in the presence of land-derived materials its production is accomplished through the intervention of foraminifera, and brought about by chemical changes which take place in the finely comminuted sediment as the result of the decomposition of the organic matter inclosed in the shells and disseminated in the surrounding mud. Glauconitic casts of foraminifera are of common occurrence in such deposits.

It will be observed, then, that two conditions are requisite for the production of glauconite. First, the deposition of mineral particles of land-derived origin; and, second, the presence of foraminifera. In the absence of either, the production of greensand evidently does not take place, while its formation is retarded and finally ceases altogether as the amount of deposited materials increases adjacent to the coast.

The conditions for the formation of greensand being then as above described, it is probable that the succession of events during the upper Cretaceous along the northern Atlantic coast was somewhat as follows: With the opening of the Matawan epoch moderately quiet, deep seas prevailed over most of the area, resulting in a slow accumulation of muddy sediments, in which locally and for brief periods the conditions were favorable for the formation of glauconite. Later in the Matawan epoch the conditions of sedimentation changed in the north, but remained much the same in the south. Thick bedded sands were laid down over the northern portion of the area, although a return to the muddy sedimentation occurred prior to the close of the epoch throughout a portion of the district, bringing with it locally conditions again favorable to the production of glauconite. The epoch closed in the north with a renewed deposition of sand, at this time, however, highly micaceous. the micaceous materials also characterizing the finer deposits of the south, as they had done to some extent the sediments of that area throughout the epoch.

With the advent of the Monmouth epoch land-derived materials were largely increased in volume in the southern portion of the district, but were only deposited for a short time in the north, where they were shortly succeeded by conditions highly favorable for the production of glauconite, with every indication of quiet and deep seas. These conditions, however, were less pronounced in proceeding southward, and over the area of southern Maryland sedimentation similar to that which had characterized the earlier portion of the epoch was continued. The epoch closed with the deposit of a great volume of sands and clays, sparsely glauconitic, throughout northern New Jersey as well as in Delaware and

Maryland, while in the intervening district of central and southern New Jersey the sedimentation was probably of a much finer character, as shown by the chocolate colored marls of that area, unless, perchance, subsequent erosion had caused the removal of all the sandy sediments.

The succeeding Rancocas epoch was a time of slow accumulation of continental materials throughout the northern Atlantic Coastal plain, so that the production of glauconite went on unhindered. During the later portion of the epoch, however, there must have been a great profusion of bryozoan life, since the deposits show a remarkably large proportion of calcareous materials, largely made up from the shells of these organisms, the percentage of carbonate of lime at times exceeding 80 per cent of the whole. The conditions most favorable for the production of these deposits were found in central and southern New Jersey, particularly in the region of Salem county.

The Manasquan epoch was characterized throughout by conditions favorable to the formation of highly glauconitic deposits, but land-derived materials in considerable amounts reached the area just at the opening of the epoch as well as in a less pronounced degree toward its close.

The Shark River epoch succeeded the Manasquan without evidence of any marked change in the physical features of the district, conditions favorable to the production of glauconite still continuing, so that if the Shark River formation is considered of Eocene age, a subject which will be later discussed, then we have no physical break between the Cretaceous and Eocene at this point.

At the close of the Shark River epoch the conditions favorable to the formation of greensand ceased throughout that portion of New Jersey which we have been hitherto considering. To the south, in Delaware and Maryland, the Eocene period was one of greensand production, and the representative of those deposits may today exist far to the southward in New Jersey, buried beneath Miocene strata, but its presence has not as yet been definitely shown in the well records.

PROBABLE CONTINENTAL RELATIONS AS REVEALED BY THE DEPOSITS.

The deposits of the upper Cretaceous afford evidence either that the land of the period was supplying little sediment to the sea or that these Cretaceous materials were laid down so far from the shoreline that but a relatively small amount could reach the area. A brief history of events just prior to the opening of the upper Cretaceous may aid in the interpretation of the continental relations during that period.

The Lower Cretaceous period is characterized by deposits which give evidence of a gradual submergence of the eastern border of the conti-

FIGURE 1.—MARL PIT NORTH OF FARMINGDALE, NEW JERSEY

Looking west; showing Manasquan formation overlain by Miocene clays.

FIGURE 2.—BEACON HILL FROM NEAR TELEGRAPH HILL, SOUTH OF KEEPORT, NEW JERSEY

FARMINGDALE MARL PIT AND BEACON HILL

nent, brought about by seaward tilting and accompanied by landward elevation, which produced increased activity in the streams. The weathered materials of the surface rocks which had become disintegrated to great depths on account of the relatively low elevation of the land in the previous period were carried seaward, thick beds of sands and clays often characterized by large amounts of arkose being formed. Several epochs of elevation and depression with variations in the angle and direction of tilting doubtless took place during the period, with the result that the land must have been considerably planed down prior to the opening of the upper Cretaceous.

The upper Cretaceous was probably ushered in by a general depression of the area draining to the Atlantic border, which must have diminished the power of the streams and at the same time decreased the supply of sediment. This was probably also accompanied by some depression of the sea-floor as well; yet from the descriptions which have been given in the previous pages regarding the character, distribution, and relations of the sediments it is evident that the continental conditions could hardly have been constant throughout the period of Upper Cretaceous deposition. Oscillations of greater or less moment, accompanied by increased activity of the streams, must have taken place from time to time, but these changes were not identical or synchronous throughout all portions of the northern Atlantic slope. At the same time many of the minor changes may find their explanation in the direction of transport brought about by variations in the oceanic currents adjacent to the continent border. Such an explanation is, however, wholly inadequate to account for the great deposits of sand in the upper Matawan of northern New Jersey, the lower Monmouth of central and southern New Jersey, Delaware, and Maryland, and the upper Monmouth of northern New Jersey and the Delaware peninsula. The largely increased deposits of coarse materials at these epochs over the wide areas indicated could only have been brought about by changes upon the adjacent land surface.

The close of the upper Cretaceous witnessed the general elevation of the entire area, the gradual stripping off of the Cretaceous cover, and the superimposition of the consequent streams upon the underlying rocks to which, under varying conditions, they have been continuing to adjust themselves during subsequent periods.

SUBSEQUENT STRUCTURAL AND CHEMICAL CHANGES IN THE STRATA.

The interpretation of the sedimentary record would hardly be complete without reference to the changes, both structural and chemical, which have taken place in the strata subsequent to their deposition. The various oscillations of the northern Atlantic Coastal plain have produced, so far as observed, no marked structural change in the Upper Cretaceous strata, although the beds have been gradually depressed seaward, so that each succeeding group of deposits has come to lie at a slightly lower angle. Slight deformation, both along the strike and dip, has been observed, the explanation for which is sought in movements which have taken place subsequent to the formation of the strata, although no doubt in part explained by the uneven surface upon which the deposits themselves were laid.

Chemical changes of considerable moment have taken place in the beds, often obscuring the original character of the strata. The most conspicuous of these alterations has been the weathering of the glauconite, which has changed the deposits from green or grayish green to brown or reddish brown in color. This is especially marked in the more porous strata or along the thinned out margins of all the formations. At times the glauconite grains have been entirely destroyed, while at other times the surface only has been weathered, and when crushed the greenish interior is shown. At times induration takes place, producing either shelly layers or thick beds of ironstone. The ironstone deposits have very materially affected the topography of the northern Atlantic Coastal plain, these hard beds protecting the underlying formations from removal. The escarpment in northern New Jersey owes its prominence very largely to the protection thus afforded.

The other deposits have also suffered greater or less change in their surface exposures, the dark clays especially becoming lighter colored as the carbonaceous materials contained in them have been changed or removed by the percolating waters.

Interpretation of the faunal Record.

CORRELATION OF THE FORMATIONS WITHIN THE PROVINCE.

The several formations of the upper Cretaceous of the northern Atlantic Coastal plain are highly fossiliferous throughout the area of their occurrence, so that, with few exceptions, the paleontological evidence is adequate for the correlation of the strata from their northern to their southern limits (plate 48).

The Matawan formation is less highly fossiliferous than the other divisions of the upper Cretaceous. At certain localities, however, the species represented are very numerous, but the fossiliferous bands are less persistent and the individuals seldom so abundant as in the succeeding formation. The several species of ammonites referred to in the list of fossils are especially characteristic of the Matawan formation, *Ammonites delawarensis* and several of the forms of *Scaphites* not having been recognized from the later horizons. Many of the other molluscan types are unknown except in the Matawan, or are found less frequently in the succeeding Monmouth. Other forms, on the other hand, occur with about equal frequency in both the Matawan and the Monmouth. A good many species hitherto recorded from the lower greensand marls are found upon examination of the localities to have come from beds beneath the Monmouth, so that a careful revision of the statements of earlier authors regarding the horizon from which the fossils have been derived is necessary. *Belemnitella americana*, so common in the Monmouth formation, has never been observed in the Matawan, while the shells of *Exogyra costata* and *Gryphæa vesicularis*, so common in the Monmouth, although occurring in the lower portion of the Matawan, are not at all frequent until the upper beds are reached.

The Monmouth formation is very rich in organic remains, both in number of species and individuals, the most common and widely distributed forms being *Gryphæa vesicularis*, *Exogyra costata*, and *Belemnitella americana*, which characterize all three divisions of the formation. Large numbers of other molluscan species, as, for example, *Ostrea larva*, *Idonearca vulgaris*, *Crassatella vadosa*, *Cardium perelongatum*, and *Turritella vertebroides*, are widely distributed, so that the faunal characters of the formation are sufficiently distinctive to establish its occurrence at all points without difficulty.

The Rancocas formation, although highly fossiliferous from the standpoint of individuals, is characterized by very few species. The most typical form is the *Terebratula harlani*, which, throughout New Jersey, is so widely found at the top of the lower greensand member, but which in Delaware and Maryland also occurs within and at the top of the limesand division. Among the characteristic forms are *Idonearca medians*, *Gryphæostrea vomer*, and the several types of Echinodermata mentioned above in the list of fossils from the Rancocas formation.

The Manasquan formation is not as rich in organic remains as the Rancocas, but there are several types which are extremely common and characteristic, among them being *Ostrea glandiformis*, *Gryphæa bryani*, *Crassatella conradi*, and *Caryatis* (?) *veta*. With few exceptions, the species are quite distinct from those of the preceding and succeeding formations.

The Shark River formation is characterized by an abundant fauna within the limited area in which it has been observed. With one or two exceptions, the forms are quite distinct from those of the preceding formations, and the genera represented point to a more recent fauna.

An examination of the faunal zones shows that some are much more sharply delimited than others. The Matawan and Monmouth faunas, for example, are much more closely connected with one another than are any of the others, and although they are really but little more than subdivisions of a general fauna, yet they are sufficiently distinct from one another to be readily followed from the Raritan bay to the eastern shore of the Chesapeake, while beyond the distinctive characters of the Matawan fauna are continued to the Potomac at Fort Washington. The Rancocas fauna is very distinct both from that above and below it, and is highly characteristic of the formation in which it occurs. Its *Terebratula harlani* zone is the most persistent fossiliferous band in the whole Cretaceous series. The Manasquan and Shark River faunas are equally distinctive, although having, so far as can be determined from surface indications, a far less wide geographical distribution. Almost no species common to earlier faunas have been found, and practically no forms continue on from the Manasquan into the Shark River epoch.

CORRELATION OF THE DEPOSITS WITH THOSE OF OTHER AREAS.

The first four formations above described have been, with a single exception, generally recognized as belonging to the upper Cretaceous, while the fifth or Shark River formation has been assigned to a later date, since Conrad* first in 1848, and again more fully in 1865, maintained the Eocene age of the deposits. More recently Whitfield † has claimed the identity of several of the species with forms found in the Eocene of the Gulf, although they occur there at somewhat widely separated horizons; but since all of the specimens thus referred are casts, he expresses some doubt as to their identity. So far as the generic relations of the molluscan types are concerned, most of them certainly have a more Eocene than Cretaceous aspect, yet many could as well be referred to the one as the other. With one or two exceptions, all have been found as early as the Cretaceous in some portions of the world. There are, it is true, no distinctively Cretaceous types, while the genus *Aturia* and one or two vertebrate types are not known earlier than the Eocene, yet it has been hitherto impossible to satisfactorily correlate the Shark River formation with any known Eocene deposits. It is, of course, readily conceivable that deposition went on in the moderately deep waters which prevailed in this region continuously during late Cretaceous and early Eocene time, but elsewhere upon the Atlantic and Gulf coasts a marked stratigraphic break occurs at or near the close of the Cretaceous, and sediments of a different type characterize the oldest of the known Eocene strata.

Some light may perhaps be thrown upon the subject by indicating the equivalents of some of the other Coastal Plain formations where the

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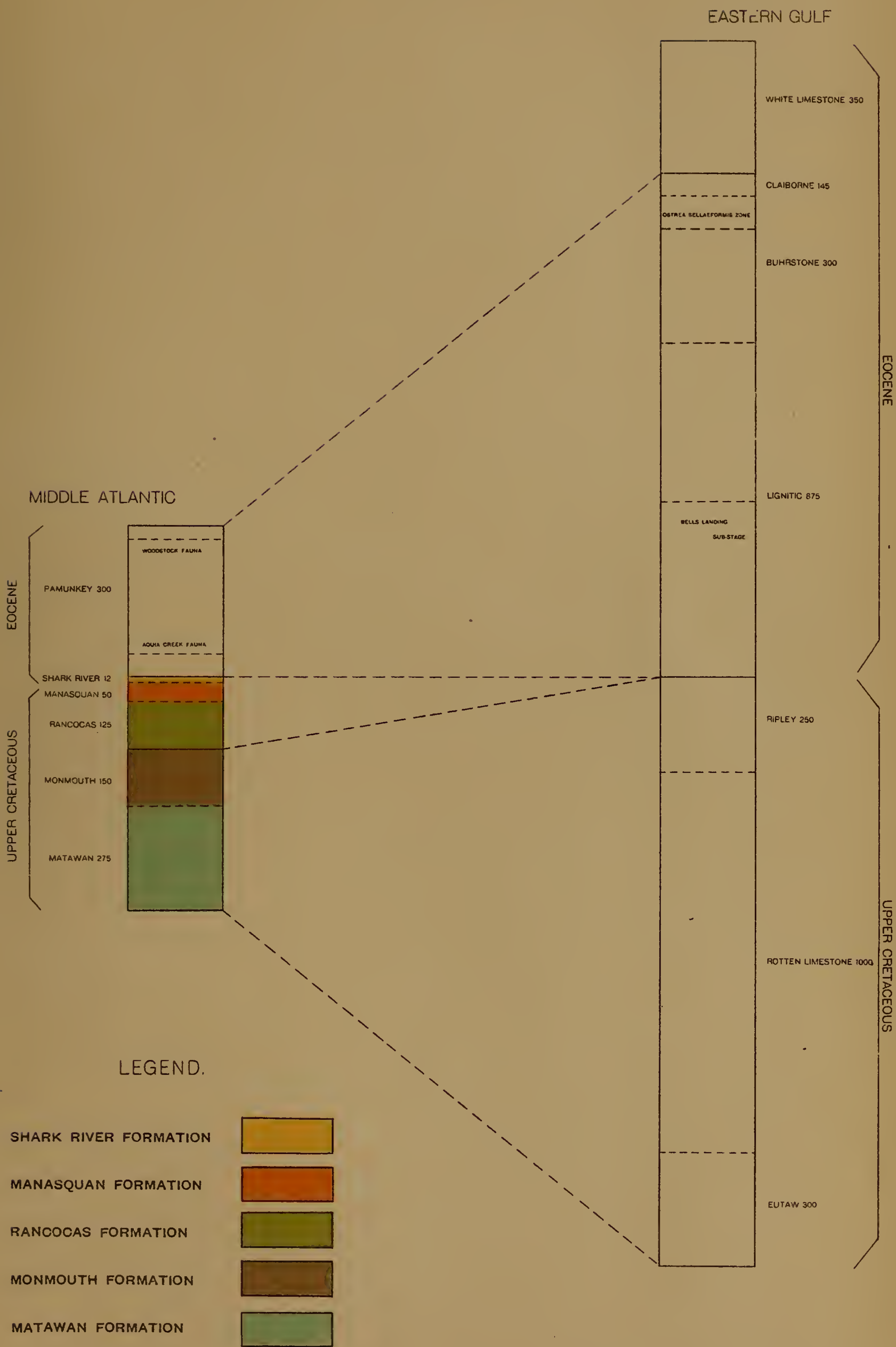
* Jour. Acad. Nat. Sci. Philadelphia, U. S., vol. 1, 1848, p. 129. Proc. Acad. Nat. Sci. Philadelphia, 1865, pp. 71, 72.

† Monograph U. S. Geol. Survey, vol. ix, 1884. Ibid., vol. xxi, 1890.

CORRELATION TABLE
No. 2.



CORRELATION OF UPPER CRETACEOUS AND EOCENE FORMATIONS IN MIDDLE ATLANTIC SLOPE AND EASTERN GULF

PHOTO LITH. BY A. HOEN & CO. BALTIMORE, MD.

criteria for correlation are more complete. The physical characteristics and organic remains of the Potomac formation of the Atlantic border have generally led to its correlation with the Tuscaloosa of the eastern Gulf, which occupies a similar position at the base of the Coastal Plain series. These basal deposits are generally regarded to be of Lower Cretaceous age and to be the sole representatives of it east of the Mississippi river.

It is highly probable that the more distinctly marine beds of the upper Cretaceous rest throughout this portion of the continental border unconformably upon the older deposits, but whether their basal strata are synchronous everywhere has not as yet been definitely proven. Enough has been learned, however, from a comparison of the species of the Matawan-Monmouth groups with the Eutaw-Rotten Limestone-Ripley groups to show that they have a common fauna. This is very clear as regards the Ripley and Rotten Limestone groups, while there is nothing in the meager assemblage of forms from the Eutaw group to debar it from being included also. Stanton has found that these Upper Cretaceous deposits in Mississippi have 86 species in common with the New Jersey strata, while in Alabama 35 have been found, all of which are also included in the list from Mississippi. At the same time 54 continue on into Texas. It is highly probable, then, that the Matawan-Monmouth formations stand as the representative of the upper Cretaceous of the eastern Gulf region.

Before considering the succeeding groups of formations (Rancocas-Manasquan-Shark River), all of which contain faunas of post-Ripley age, let us examine the typical Eocene fauna of the Pamunkey formation of Delaware, Maryland, and Virginia, which is the next succeeding member of the Coastal Plain series. A critical examination of the fossils from this formation shows two quite distinct faunal zones. The lower, about 60 feet from the bottom of the formation in the Potomac valley, has been designated the Aquia Creek fauna, and shows many points of similarity to the middle Lignitic of the Gulf, while the upper or Woodstock fauna, containing *Ostrea sellæformis* and other types, finds its approximate equivalent in the Claiborne, or rather that zone represented below the fossiliferous sands. With proper allowance for differences in physical conditions and the consequent effect upon geological range of species, for time occupied in migration, and for the lack of typical forms in the highest and lowest strata, the Pamunkey may be regarded as the equivalent of all or the major part of the Lignitic, Burhstone, and Claiborne of the Gulf, although no assumption is made that deposition began at just the same time in the one region as in the other. Some portions of the basal

Lignitic may have antedated the lower bed of the Pamunkey, but that is not at all sure.

Let us now return to a consideration of the Rancocas-Manasquan-Shark River formations. The Rancocas fauna, so far as its generic forms are concerned, as well as in a few instances of specific identity, is clearly Cretaceous, but from its position is later than the Ripley. The Manasquan fauna, which succeeds it in conformable deposits, is far less typically Cretaceous, although it could hardly be associated with the Eocene, while the conformably succeeding Shark River bed, only 12 feet in thickness, has a fauna which shows unmistakable Tertiary affinities.

It seems highly probable that the conformable Rancocas-Manasquan-Shark River group may occupy a position between the Ripley and the Lignitic of the Gulf, and may be in its two basal members of Cretaceous and in its upper member of Eocene age. Clearly defined unconformity exists between the Ripley and the Lignitic, and during the interval represented by this physical break deposition must have taken place somewhere along the continental border. It is highly probable that the Rancocas-Manasquan-Shark River group represents the whole or a part of this interval (plate 50).

To the north of New Jersey there are many indications of the former wide extension of the Upper Cretaceous formations. On both Staten island and Long island, fossils belonging to the Matawan-Monmouth fauna have been obtained from the drift, while the deposits are still found in place on Block island, Marthas Vineyard, and at Marshfield, in Massachusetts. It seems highly probable that the deposits of all these localities belong to the Matawan formation. To the south of Maryland, in eastern Virginia, the upper Cretaceous has been penetrated in well-borings, but the records are not sufficiently complete to determine the horizons with accuracy. In North and South Carolina the presence of the upper Cretaceous has been known for a long time. The fossils described from this district show that the Matawan-Monmouth fauna is represented, but it is not certain whether the same divisions exist there as in the northern Atlantic states. Nothing similar to the higher formations of the upper Cretaceous in New Jersey and Maryland has apparently been observed.

Some statements regarding the approximate equivalents of these American formations among western European deposits may well close this chapter. Any attempt at a detailed correlation of the strata must, from the necessities of the case, be fraught with many difficulties. Almost none of the species are identical, yet the assemblage of forms is such as to warrant the conclusion that we have in the New Jersey formations the representatives of the Cretaceous stages of the Senonian and the Danian as well as the very earliest stage of the Eocene of Europe.

The Matawan-Monmouth fauna has many strong Senonian affinities in its cephalopod and pelecypod forms, while the Rancocas and less distinctly the Manasquan point to the Danian. It is interesting to note that the lower Danian, known as the Maestrichtian or Maestricht chalk, also has an extensive development of Bryozoan marls very similar in character to the Vincentown lime-sands, while its paleontological affinities are much the same.

Regarding the equivalents of the Shark River fauna, there is much greater obscurity. In its paleontological relations to the underlying formations it is not unlike the *Calcaire pisolitique* of France, in which the general aspect of the fauna resembles the oldest Tertiary, although a number of undoubted Cretaceous species still persist. These deposits are put in the substage Garumnian as the upper member of the Danian by European geologists. It is possible that the Cretaceous affinities of the Garumnian are somewhat closer than those of the Shark river, but one or two characteristic Cretaceous forms are thought to persist in the latter also. On the whole, however, it seems best to consider the Shark River fauna as approximately the representative of the basal Eocene of Europe, since the assemblage of forms points so strongly to their Tertiary affinities. Further than that it is impossible to go.

At best the correlation of the American Coastal Plain formations with European must be of the most general character, in which the broader affinities of the faunas only are shown. The wide difference in conditions is such as to preclude detailed comparisons of the deposits upon the opposite sides of the Atlantic.

Economic Products.

The economic products of the Upper Cretaceous formations are confined largely to the sands and clays which have been extensively worked for brick-making, and to the greensand marls, which for over a century have been used as fertilizers.

The workable sands and clays come entirely from the Matawan formation and mainly from its lowest member, the Crosswicks clays. These deposits are extensively worked in New Jersey at the present time, along the banks and in the vicinity of Matawan creek, in Monmouth county; upon Crosswicks creek and near Bordentown and Kinkora, in northern Burlington county, as well as upon Pensauken creek near Lenola, in its southern part; a few miles to the east of Camden, in Camden county, and at Woodbury, in Gloucester county. Many millions of bricks are annually produced at these places.

The Matawan formation in New Jersey has also been worked in its more glauconitic layers, both in the Crosswicks clays and Hazlet sands, for greensand marl, but very little is being done at the present time.

The workable marls come chiefly from the succeeding formations, all of which, from the Monmouth to the Shark river, have produced valuable fertilizers throughout the area of their occurrence. The Monmouth formation was the earliest worked, and extensive pits were opened in Monmouth county, New Jersey, where it is most highly glauconitic. Throughout central and southern New Jersey little digging has been done at this horizon, as the deposits become too argillaceous; but in Delaware, especially in the vicinity of the Chesapeake and Delaware canal, the thin but very marly layers have yielded thousands of tons in quite recent years.

The Rancocas formation, more particularly in its lower division, has been worked for marl at several points in Monmouth county, especially in the southwestern part, at and near Hornerstown. It has been most largely developed for this purpose in recent years, however, in the more southern counties of the state, at Blackwood, in Camden county; at Sewell and Mullica Hill, in Gloucester county, and about Woodstown, in Salem county. The same beds have been worked to some extent in Delaware and on the eastern shore of Maryland, particularly in the valley of the Sassafras river.

The marl richest in fertilizing ingredients belongs to the Manasquan formation, which, with the Shark River formation, which overlies it, has been worked largely in eastern Monmouth county (plate 49, figure 1). The Squankum marl, so called, obtained near Farmingdale, has been extensively exported and is in high repute. Very large pits were also opened at Vincentown, Burlington county, and are still worked to some extent.

The greensand marls were first used as fertilizers in 1768, the first recorded pit being opened near Marlboro, Monmouth county, New Jersey. It was not, however, until 1820 that the marl came into general use, and for the next half century millions of tons of it were employed for agricultural purposes. Much of it was dug from small openings for local consumption by the land-owners whose farms were in the marl district, or was hauled by wagons into the neighboring county. A great number of larger pits were opened by companies engaged in the marl trade, the railroads oftentimes building branch tracks into the excavations. Thousands of carloads were thus removed directly from the pits and shipped to distant points. During the last 25 or 30 years, since the commercial fertilizers have come into such general favor, the marl industry has waned, to the great disadvantage of the Jersey farmer. Recently something of a revival has taken place, and the local use of the marl seems to be increasing annually.

Another economic product of some importance is the calcareous deposit which characterizes the Vincentown lime-sand of the Rancocas formation, and which has been burned for lime at several points in south Jersey. It is largely consumed locally.

The indurated ferruginous layers of the Matawan and Monmouth formations are also used locally for building purposes, in the absence of more suitable materials. The more highly calcareous and ferruginous materials of all the formations are also employed to some extent for road construction, although the superficial Pensauken gravels are better suited and are more extensively used.

SUMMARY.

The leading conclusions contained in this paper are as follows:

1. A marked westerly facing escarpment, called "the Cretaceous escarpment," accompanies and characterizes the Upper Cretaceous formations.

2. The several formations show sufficiently marked differences in the character of their materials throughout the entire distance from northern New Jersey to southern Maryland to readily distinguish them.

3. The formations, with some local exceptions, thin toward the south and at the same time change considerably in their lithologic characters.

4. The subdivisions of the different formations, clearly defined at certain points, are unrecognizable at others. In general they grow less distinct toward the south.

5. The formations are gradually overlapped one after another toward the south, until in the Potomac valley the Tertiary deposits rest directly upon the Lower Cretaceous.

6. An unconformity is found between the Potomac and Matawan formations, a probable one between the Monmouth and Rancocas formations, and a clearly marked one between the Shark River and later deposits.

7. The faunal characteristics of the formations are clearly defined throughout the region, the Matawan-Monmouth faunas being more closely related to one another than the Rancocas-Manasquan-Shark River faunas, while the latter as a whole are sharply defined from the former.

8. The Matawan-Monmouth faunas, which range through a conformable group of deposits 400 feet in thickness, are the equivalent of the

Eutaw-Rotten Limestone-Ripley faunas of the Gulf, which occupy strata aggregating 1,600 feet in thickness, and which rest probably unconformably upon the Tuscaloosa formation, the southern representative of the Potomac.

9. The Rancocas-Manasquan-Shark River faunas, occupying a conformable series of beds less than 200 feet in thickness, are absent in the Gulf, and probably represent the time-break between the upper Cretaceous and Eocene in that region, since the Pamunkey fauna has already been shown to represent approximately the Lignitic-Buhrstone-Claiborne (Lower and Middle Eocene) of the same district.

10. When compared with European horizons the Matawan-Monmouth fauna is probably Senonian and the Rancocas-Manasquan is Danian in age, while the Shark River fauna must be regarded as lowest Eocene, although showing some affinities to the *Calcaire pisolitique* of France, which is commonly held to be upper Danian.

11. The economic products are confined largely to Matawan sands and clays, which have been extensively worked for brick-making, and to Monmouth-Rancocas-Manasquan-Shark River greensand marls, which have for over a century been used as fertilizers.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 8, PP. 359-446, PL. 51 APRIL 30, 1897

PROCEEDINGS OF THE NINTH ANNUAL MEETING, HELD AT WASHINGTON, DECEMBER 29, 30, AND 31, 1896

HERMAN LE ROY FAIRCHILD, *Secretary*

CONTENTS

SESSION OF TUESDAY, DECEMBER 29

The Society was called to order at 10 o'clock a m, in the lecture hall of the United States National Museum, where all the daily sessions were held, President Joseph Le Conte in the chair. Mr Charles D. Walcott, Director of the United States Geological Survey, made a brief address of welcome, and suggested that the Society should establish the custom of holding its meetings in Washington very frequently. After a few words of response, the President introduced the administrative business by a call for the report of the Council. This was submitted in print by the Secretary and copies were distributed to the Fellows.

REPORT OF THE COUNCIL

To the Geological Society of America,
in Ninth Annual Meeting assembled:

During the past year the Council has found it necessary to hold only its stated meetings in connection with the Philadelphia and Buffalo meetings of the Society. The Council congratulates the Society that the prevailing financial distress of the past year has not seriously affected the membership and finances of the Society, and that in all respects the Society is in a very prosperous condition, as will be shown by the reports of the executive officers.

The Council recommends that the rules be so changed as to make the Editor an *ex officio* member of the Council.

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The records of the two meetings of the Society, at Philadelphia and Buffalo, are printed in the Proceedings and require no repetition here. The experiment of holding only an administrative session at the summer meeting, allowing all papers to be read in Section E of the American Association for the Advancement of Science, and of offering several excursions open to the public, was not altogether satisfactory. At Buffalo the Society practically effaced itself for the time, but to the decided advantage of Section E, which had a full program. The excursions were not well supported. Of the four offered two were abandoned and the other two were not sufficiently attended to compensate for the labor and expense. For the next summer meeting a different plan is proposed, the Society to occupy a portion of the time of Section E.

Membership.—The Society has lost three more names from the roll by death. Robert Hay died December 14, 1895; Charles Wachsmuth died February 7, 1896, and N. J. Giroux died November 30, 1896. To the 228 names of Fellows in the last printed list (April, 1896) must be added the following names of six Fellows elected at the Summer meeting, all of whom have qualified: J. G. Aguilera, Philip Argall, Ezequiel Ordonez,

T. W. Vaughan, H. S. Washington, G. H. Ashley. With the omission of the name of Mr Giroux this makes a total of 233 Fellows. Six Fellows are now so in arrears for dues that they are liable to be dropped from the roll. The names of eight candidates for Fellowship are before the Society, and six new applications are on file with the Secretary. It will be observed that notwithstanding the financial depression the number of Fellows two years or more in arrears for dues is less than last year, and that the total membership steadily increases.

Distribution of Bulletin.—The total distribution of the Bulletin, both by volumes and brochures, is more significant than the figures for the year, simply, which latter can be found by comparing the following table with the corresponding table in last year's report. In this table the several volumes formerly "held for exchanges" are included in the reserve:

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING THE YEARS 1891–1896

Complete Volumes

	Vol. 1.	Vol 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.
Distributed to Fellows	..	....	209	214	214	223	222
Donated to "exchanges"	90	90	88	88	88	86	84
Sold to libraries	77	77	79	75	71	76	67
Sold to Fellows	19	15	9	5	3	1	....
Sent to Fellows to supply deficiencies	2	1	1	....	....	....	....
Donated	4	4	3	2	2	2	1
Bound for officers and library	3	3	3	3	3	3	3
Volumes in reserve	69	316	360 (?)	363 (?)	353	109 (?)	123 (?)
Number of complete volumes received	264	506	750 (?)	750 (?)	734	500 (?)	500 (?)

Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.
Sent to Fellows to supply deficiencies	48	132	45	43	26	10	2
Sent to libraries to supply deficiencies	..	7	4	3	1	1	2
Sold to Fellows	16	20	5	13	17	6	1
Sold to the public	11	12	12	9	4	4	6
Donated	3	3	3	3	2	....	....

Subscriptions.—The number of regular subscribers to the Bulletin has increased somewhat during the year, being now 65 as against 59 in the last report. Of these 26 receive the brochures and 39 the complete volumes. As the list of subscribers has never been published it is here included.

Ann Arbor—University of Michigan.
Auburn—Alabama Polytechnic Institute.
Baltimore—Johns Hopkins University.
Berkeley—University of California (brochures).
Berlin—R. Friedlander & Sohn.
Blacksburg—Virginia Agricultural and Mechanical College.
Bloomington—Indiana University.
Boston—Boston Public Library (brochures).
Boston—Massachusetts Institute of Technology (brochures).
Boston—Massachusetts State Library.
Brooklyn—Brooklyn Library.
Buffalo—Buffalo Library.
Burlington—University of Vermont (brochures).
Cambridge—Museum of Comparative Zoology (brochures).
Cedar Falls—Iowa State Normal School.
Champaign—University of Illinois (brochures).
Chapel Hill—University of North Carolina.
Chicago—Chicago Public Library.
Cincinnati—Public Library of Cincinnati.
Cleveland—Adelbert College, Western Reserve University (brochures).
Cleveland—Case School of Applied Science (brochures).
Clinton—Hamilton College (brochures).
Columbus—Ohio State University.
Concord—New Hampshire State Library.
Detroit—Detroit Public Library.
Germantown (Philadelphia)—Friends' Free Library (brochures).
Glasgow—James Maclehose & Sons.
Hamilton—Colgate University.
Houghton—Michigan Mining School (brochures).
Iowa City—State University of Iowa.
Ithaca—Cornell University (brochures).
Lawrence—University of Kansas.
London—British Museum (by Dulau & Co.) (brochures).
Madison—University of Wisconsin.
Minneapolis—Minneapolis Athenæum.
Minneapolis—University of Minnesota (brochures).
Montreal—McGill University.
Morgantown—West Virginia University.
Mount Vernon—Cornell College (brochures).
New York—American Geographical Society.
New York—Columbia University (brochures).
New York—Cooper Union (brochures).
New York—New York Public Library (brochures).
Ottawa—Library of Parliament (by Charles Scribner's Sons, New York).
Philadelphia—Franklin Institute.
Princeton—Princeton University (brochures).
Providence—Brown University.
San Francisco—California State Mining Bureau.
San Francisco—Mechanics' Institute (brochures).

San Francisco—San Francisco Free Public Library (brochures).
Seattle—University of Washington.
South Bethlehem—Lehigh University.
Springfield (Massachusetts)—City Library.
Springfield (Illinois)—Geological Survey of Illinois (brochures).
Stanford University—Leland Stanford, Jr., University (brochures).
State College—State College (Pennsylvania), Department of Mining Engineering (brochures).
Stockholm—Samson & Wallin (brochures).
Strasburg—Trübner's Buchhandlung & Antiq.
Sydney—Public Library, New South Wales.
Terre Haute—Indiana State Normal School (brochures).
Toronto—University of Toronto.
Washington—United States National Museum.
Wilkesbarre—Osterhout Free Library.
Wilkesbarre—Wyoming Historical and Geological Society.
Worcester—Worcester Free Public Library.

Bulletin Sales.—Notwithstanding the financial stringency, the receipts from the sale of the Bulletin during the year 1896 exceed those of any former year, amounting to $695.75. It would seem certain that an average of at least $500 per year can be relied upon from the sale of the Bulletin as available to support the publication. The Secretary suggests the desirability of using available funds upon the Bulletin as the surest way of sustaining its commanding position and of increasing its sales.

RECEIPTS FROM SALE OF BULLETIN DURING 1896

By Sale of Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Total.	
From Fellows	$9 00	$4 50	$4 00	....	....	....	....	$17 50	
From libraries	45 00	45 00	45 00	$45 00	$45 00	$85 00	$290 00	600 00	
Total for 1896	54 00	49 50	49 00	45 00	45 00	85 00	290 00	617 50	
By last report (1895)	416 60	409 00	384 50	352 50	327 00	304 00	35 00	2,228 60	
Total to date	$470 60	$458 50	$433 50	$397 50	$372 00	$389 00	$325 00		$2,846 10

By Sale of Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Total.	
From Fellows	$2 15	$1 45	$0 40	$1 65	$1 25	$0 25	$0 50	$7 65	
From public	....	1 00	4 50	2 00	0 40	1 70	6 00	15 60	
Total for 1896	2 15	2 45	4 90	3 65	1 65	1 95	6 50	23 25	
By last report (1895)	20 90	16 60	5 85	5 55	3 90	2 25	....	55 05	
Total to date	$23 05	$19 05	$10 75	$9 20	$5 55	$4 20	$6 50		$78 30

Grand total	$2,924 40
Received for volume 8 in advance	50 00
Received for volume 9 in advance	5 00
Total receipts to date	$2,979 40
Charged and uncollected	37 00
Total sales of Bulletin to date	$3,016 40

COMPARATIVE TABLE OF TOTAL RECEIPTS

Received for Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Total.	
From Fellows	$85 60	$68 50	$36 50	$17 50	$12 00	$4 00	$ ——	$224 10	
From libraries	385 00	390 00	397 00	380 00	360 00	385 00	325 00	2,622 00	
Total	$470 60	$458 60	$433 50	$397 50	$372 00	$389 00	$325 00		$2,846 10

Received for Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Total.	
From Fellows	$8 60	$6 80	$1 35	$2 50	$4 15	$2 50	$0 50	$24 10	
From public	14 45	12 25	9 40	6 70	1 40	1 70	6 00	51 90	
Total	$23 05	$19 05	$10 75	$9 20	$5 55	$4 20	$6 50		78 30
Total for seven volumes									$2,924 40

Exchanges.—Three addresses have been removed from the list of "Exchanges." The Annuaire Géologique Universel, Paris, and the Geological Record, London, have suspended publication, and the Geological Society of Tokyo, Japan, has disbanded. The present number of exchanges is 84, of which 11 receive brochures. It should be noted that we have no exchanges in Mexico or in Central America and no subscribers in those countries.

Library.—There is nothing special to state concerning the library. The accessions have been duly recorded in the proceedings.

The Fellows should be reminded that the library material is at their service. Communications should be addressed to Mr Charles Orr, Case Library, Cleveland, Ohio.

Expenses.—The expenses of the Secretary's office have been considerably less than during any former year, and only two items are equal to those of last year. The stationery and printing account is slightly in excess, on account of the expensive circular of the summer excursions. As many libraries persist in sending local checks in payment of the Bulletin, there is a small expense for the collection of checks, trifling, however, compared with the interest allowed by the bank on the deposits of Bulletin receipts.

EXPENDITURE OF SECRETARY'S OFFICE FOR THE SOCIETY'S FISCAL YEAR, NOVEMBER 30, 1895, TO NOVEMBER 30, 1896

Account of Administration

Postage	$29 00	
Expressage	2 30	
Stationery and records	1 50	
Printing, including stationery	108 95	
Meetings	2 26	
Library	7 26	
Total		$151 27

Account of Bulletin

Postage (and two telegrams)	$80 02	
Expressage and freight	51 34	
Wrapping material	0 75	
Collection of checks	4 30	
Total		$136 41
Total expenditure		$287 68

All of which is respectfully submitted.

H. L. FAIRCHILD,
Secretary.

ROCHESTER, NEW YORK, *December 20, 1896.*

TREASURER'S REPORT

To the Council of the Geological Society of America:

The accompanying statement of receipts and disbursements for the year (December 1, 1895, to December 1, 1896) just closed exhibits the present financial condition of the Society.

The invested funds remain the same as in last statement, viz, $2,900, yielding $168 annual interest. The item of $19.94 "interest" is the amount paid by the Security Trust Company of Rochester, New York, as interest at 4 per cent on the Society's monthly balances deposited with that institution. It is the policy of the Treasurer to keep as large a balance as possible in the Rochester bank, where the Secretary places all proceeds from the "sales of publications." The Bank of the Monongahela Valley at Morgantown, in which all membership and other dues are deposited, does not pay interest on balances, but in lieu thereof makes no charge for collecting nearly 200 checks annually from all parts of the country, thus indirectly paying 3 to 4 per cent on the Society's daily balances. The $100 time certificate of deposit reported in the last statement of the Society's funds was cashed during the year and the proceeds credited to receipts for the year, as may be seen below.

During the year the names of five Fellows have been dropped from the roll for non-payment of dues, while two others are in arrears for three years, but their names retained on the roll at their request on promise of payment, which has not yet been fulfilled. Four Fellows are delinquent for 1895 and 1896, while thirty-two, a much larger number than ever heretofore, are still delinquent for the current year, 1896, only. It would be a great convenience to the Treasurer and a good thing for the Society if Fellows would remit promptly on receipt of the first bills, in January of each year, since the April, July and October notices find many of the Fellows scattered over the country in field-work, or away from their usual address and means of payment, so that if notices are received under such circumstances no attention is given them in the majority of cases, and the matter is neglected entirely.

The following balance sheet tells its own story of the operations of the treasury for the past year:

RECEIPTS

The receipts from all sources have been as follows:

Balance in the treasury November 30, 1895		$723 45	
Fellowship fees, 1894, 3	$30 00		
" " 1895, 17	170 00		
" " 1896, 167	1,670 00		
" " 1897, 1	10 00		
		1,880 00	
Initiation fees, 12		120 00	
Interest on investments:			
Tioga township, Kansas, bonds	$70 00		
Cosmos Club bonds	80 00		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Time deposit, Bank of Monongahela Valley, Morgantown, West Virginia	3 06		
Interest on deposits with Security Trust Company, Rochester, New York	19 94		
		191 00	
Sales of publications by the Secretary:			
Deposited with Security Trust Company, Rochester, New York		638 45	
Assessments, cost of publications:			
On account of illustrations	$34 80		
On account of printing	56 00		
		$90 80	
Certificate of deposit in Bank of Monongahela Valley cashed		100 00	
Total amount of receipts			$3,743 70

DISBURSEMENTS

Expenses of Secretary's office:		
Account of administration	$151 27	
Account of Bulletin	136 41	
Allowance (to include ordinary traveling and clerical expenses)	300 00	
		$587 68
Expenses of Editor's office:		
Allowance (to include personal and office expenses)		160 00
Expenses of Treasurer's office:		
Printing		5 35

Publication of Bulletin, volume 7:			
Printing	$1,508 33		
Engraving	155 76		
		$1,664 09	
Photograph account:			
George P. Merrill		11 95	
Expenses of excursions, summer meeting:			
J. F. Kemp	$15 76		
Charles H. Smyth, Jr.	13 42		
H. L. Fairchild	10 58		
		39 76	
Total amount of expenditures			$2,468 83
Balance in treasury December 1, 1896			$1,274 87

The invested funds of the Society are as follows:

On account of publication fund:		
April 1, 1891, one Tioga township, Kansas, bond, cost $1,140.26	$1,000 00	
January 29, 1892, eight 5 per cent Cosmos Club bonds at par, cost $800	800 00	
February 26, 1892, one 5 per cent Cosmos Club bond, with accrued interest, cost $100.35	100 00	
February 3, 1893, seven 5 per cent Cosmos Club bonds at par, cost $700	700 00	
May 1, 1895, two 10-20 gold bonds of Kingwood, Tunnelton and Fairchance railroad, bearing interest from January 1, 1895, cost $204	200 00	
September 27, 1895, one bond of Kingwood, Tunnelton and Fairchance railroad, with interest from July 1, 1895, cost $100	100 00	
		$2,900 00

Respectfully submitted.

I. C. White,
Treasurer.

Morgantown, W. Va., *December 7, 1896.*

Editor's Report

To the Council of the Geological Society of America:

The Editor takes pleasure in stating that, thanks to the cooperative spirit shown by the publishing members, volume 7 was completed by April 21, thus conforming to what has become the fixed policy of the Society, namely, the prompt publication of accepted manuscripts.

The fact that only one paper of the Buffalo meeting has thus far been placed in the Editor's hands suggests that the material from the summer meeting will be limited. This paper and the Proceedings brochure, making in all some 30 pages, will be in type, if not ready for distribution, before the winter session. At this time last year 260 pages of the Bulletin were published.

It is very gratifying to announce continued improvement in the form of manuscripts presented, and to note that there is so little in the relations of authors and Editor to call forth comment. On the score of economy and to secure the largest diversity of papers, greater condensation is still strongly urged.

As a guide to the Publication Committee and as a matter of interest to the members, a synopsis is given of volume 7, showing approximately the number of pages devoted to the various branches of geological research. It is needless to state that systematic classification is not attempted.

Terminology	1 page
Dynamic geology	3 pages
Economic geology	4 "
Relation of geology to pedagogy	12 "
Stratigraphic geology	21 "
Memoirs of deceased members	28 "
Areal geology	38 "
Petrology	40 "
Physiographic geology	53 "
Official matter	56 "
Rock decomposition	74 "
Glacial geology	105 "
Paleontology	123 "
Total	558 "

The cost of each of the seven volumes thus far issued by the Society is as follows:

	Vol. 1. (pp. 593; pls. 13)	Vol. 2. (pp. 662; pls. 23)	Vol. 3. (pp. 541; pls. 10)	Vol. 4. (pp. 458; pls. 10)	Vol. 5. (pp. 665; pls. 21)	Vol. 6. (pp. 528; pls. 27)	Vol. 7. (pp. 558; pls. 24)
Letter-press...	$1,473 77	$1,992 52	$1,535 59	$1,286 39	$1,887 21	$1,341 93	$1,463 60
Illustrations...	291 85	463 65	383 35	173 25	178 40	221 62	200 24
	$1,765 62	$2,456 17	$1,918 94	$1,459 64	$2,065 61	$1,563 55*	$1,663 84*

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

WASHINGTON, D. C., *December 20, 1896.*

Upon motion of the Secretary, it was voted to lay the report of the Council upon the table for one day.

* The actual cost to the Society was $77.50 less for volume 6, and $90.80 less for volume 7, those amounts being paid by authors for illustrations and correction charges.

As the Auditing Committee, to examine the accounts of the Treasurer, the Society elected Arnold Hague and James F. Kemp.

ELECTION OF OFFICERS

The result of the balloting for officers for 1897, as canvassed by the Council, was announced by the Secretary, and officers were declared elected as follows:

President:

EDWARD ORTON, Columbus, Ohio.

First Vice-President:

J. J. STEVENSON, New York, N. Y.

Second Vice-President:

B. K. EMERSON, Amherst, Mass.

Secretary:

H. L. FAIRCHILD, Rochester, N. Y.

Treasurer:

I. C. WHITE, Morgantown, W. Va.

Editor:

J. STANLEY-BROWN, Washington, D. C.

Councillors (term expires in 1899):

J. S. DILLER, Washington, D. C.
W. B. SCOTT, Princeton, N. J.

ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was announced, and the following persons were declared elected Fellows of the Society:

RUFUS MATHER BAGG, A. B., Ph. D., Baltimore, Maryland. Assistant in Geology, Johns Hopkins University.

ERWIN HINCKLEY BARBOUR, A. B., Ph. D., Lincoln, Nebraska. Professor of Geology in University of Nebraska and Acting State Geologist.

SAMUEL WALKER BEYER, B. Sc., Ph. D., Ames, Iowa. Assistant Professor in Geology, Iowa Agricultural College.

Arthur P. Coleman, Ph. D., Toronto, Canada. Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario.

Henry Stewart Gane, A. B., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada. Professor of Mining, McGill University.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

Mr S. F. Emmons, for the Local Committee on entertainment of the Society, made announcements regarding the daily lunch to be served in the building, the subscription dinner, and an invitation to the hospitality of the Cosmos Club.

The President then called for the reading of biographic sketches of Fellows who had died during the past year. The following memoir of Robert Hay was read by the author:

MEMOIR OF ROBERT HAY

BY ROBERT T. HILL

Professor Robert Hay, a founder of this Society, died on Saturday afternoon, December 14, 1895, at his home in Junction City, Kansas.

Professor Hay was born of Scottish ancestors in Lancashire, England, in May, 1835. His education was begun in the private schools of his native town, Ashton-Underlyn, and finished at the College of London, where he pursued a special scientific course, taking honors, under the late Professor Huxley.

He familiarized himself with the geology of his own and adjacent counties of England during walking tours in the long vacations. The first years of his manhood were devoted to the profession of teaching.

In 1871 he migrated to Kansas and began his long career as a teacher in the public schools of that state. From the time of his arrival until his death he was engaged in educational work of some sort. At first he took charge of the public schools of Ogden as principal, and afterwards served at Holton and at Chetopa in the same capacity.

While thus obtaining a means of livelihood he began to turn his attention to the development of the state through its natural resources, and from thence on he threw his whole lot to this end, and every subsequent act of his life showed that it was his most sincere desire to see her prosper.

After 10 years of service in the public schools he entered the employ of the state as Geologist of the State Board of Agriculture and investigated and reported upon the resources of Kansas. He visited all parts of the state, and the various reports and articles which he wrote while engaged in this work are well known and have great scientific value.

One of his old time friends said of him that there was no other man in Kansas who had been in perhaps every township of it, or nearly so, and who knew more of the state, her resources and beauties.

As state geologist he made careful preliminary investigations of the mineral deposits—lead, zinc, salt, coal—and also the natural gas. This work is embodied in reports to the State Board of Agriculture and in the proceedings of the Kansas Academy of Science.

From time to time he was employed upon special researches by the United States government. The first of these undertakings was that of making a preliminary survey along the southern border of Kansas.

In 1890 he was made Geologist-in-charge of the artesian investigation of the Great Plains region conducted by the Department of Agriculture. A large and valuable report resulted from these labors. During the last year of his life he was employed to write a special report on the underground waters of western Kansas for the United States Geological Survey.

He was for some time a member of the board of editors of the American Geologist, a member of the American Association for the Advancement of Science, and a founder of this organization. For 18 years he belonged to the Kansas Academy of Science, and prepared for it a complete bibliography of the geological works published in and about the state.

Professor Hay was an indefatigable worker. His results, largely the product of voluntary research, were produced in the face of those obstacles which necessarily confront a scientific worker on the frontiers of knowledge, but they came from one who studied nature because of his deep love for it.

His contributions to the geology of the Kansas and Plains regions have been of great service. They were largely of a reconnoissance and introductory character, rather than complete expositions of detail. Although future work may greatly refine his results, they have been of inestimable value not only as additions to our knowledge of the geography and the distribution and sequence of the formations of Kansas, but in many cases by reason of the new and original deductions they contain.

His scientific papers embrace some 30 titles, principally upon geologic subjects. His works have been of especial interest in giving a conception of the nature of the Tertiary Plains formations, which he has described in several papers. Two of his most interesting papers have been printed since his death. They are "Geology of the Fort Riley Military Reservation"* and "Water Resources of a Portion of the Great Plains."†

By a strange fatality the opportunities for perfected publication of the two chief works of his life were interrupted. Just as the proofs of his

* Bulletin no. 137 of the U. S. Geological Survey.

† Sixteenth Annual Report of the U. S. Geological Survey.

report as geologist in charge of the special artesian and underflow investigation, conducted under the auspices of the Agricultural Department, were ready to be placed in his hands in Washington he was called to his Kansas home to attend the last illness of his wife, and that report went to press full of typographical errors and without his final revision. It is a singular coincidence that his own death prevented his seeing the proofs of the paper on the geology of the Fort Riley Military Reservation, which has only recently appeared.

In personal appearance and deportment Professor Hay was plain, modest, and unassuming; in character gentle, religious, and irreproachable. I had the pleasure of being intimately associated with him and of knowing him in the office, at his home, and in the field, and I am glad of this opportunity to testify to these qualities. He was void of guile or vindicativeness, and while keenly feeling the force of certain anonymous attacks upon some of his writings, he displayed no feelings of revenge, but pursued the even tenor of his way, calm and content in the knowledge that he had worked for the right, that he had intentionally injured no one, and that time would vindicate him, as it has done.

For many years of his life he had a helpful companion in his wife, a lady of unusual literary and artistic merit, who was deeply interested in and associated with her husband's labors. She died about four years ago. Most of his papers were illustrated by her hands.

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* Prepared by Miss Jean M. Hay, of Junction City, Kansas, the surviving daughter of Professor Hay.

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Notes on some new species of fossil cephalopods: *Trans. Kansas Acad. Sci.*, vol. xiii, 1892, pp. 37–47. Description of species occurring in the Carboniferous and Permo-Carboniferous of Kansas.
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Sandstone dikes in northwestern Nebraska: *Bull. Geol. Soc. Am.*, vol. 3, 1891, pp. 50–55, figs. 1–5. Briefly describes the geologic formations of the region and states the width and direction of the two dikes.
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The river counties of Kansas. Some notes on their geology and mineral resources: *Trans. Kansas Acad. Sci.*, vol. xiv, 1893-1894 (published in 1896).

Water resources of a portion of the Great Plains: *Sixteenth Ann. Rep. U. S. Geol. Survey*, pt. ii, pp. 535–538, pls. xl–xlii, figs. 58–65. Describes the hydrographic, geologic, and topographic features and water-bearing formations of a portion of western Kansas and Nebraska and eastern Colorado.

The geology of the Fort Riley military reservation and vicinity, Kansas: *Bull. U. S. Geol. Survey*, no. 137, Washington, 1896, 8°, 35 pp. 8 pls.

In the absence of the author, the following memorial was read by Joseph Stanley-Brown:

MEMOIR OF CHARLES WACHSMUTH

BY SAMUEL CALVIN

Burlington, Iowa, has long been classic ground to the paleontologist, particularly to the student of that special branch of paleontology which deals with the most beautiful of all the fossil forms, the crinoids. Among those who have contributed to bringing the paleontologic treasures of Burlington to the attention of the scientific world we find the illustrious names of Owen, Shumard, Hall, White, Meek and Worthen. When these men had reached the zenith of their fame, Charles Wachsmuth, a man of simple, unobtrusive habit, scarcely known outside a narrow circle of intimate friends, was beginning to study the rare and beautiful forms which the quarries and natural rocky cliffs in the vicinity of Burlington afforded.

Enfeebled health and the hope of finding relief in out-of-door exercise furnished Mr Wachsmuth the motive for beginning the work of collecting crinoids; but possessing a refined taste and keen appreciation of the beautiful either in nature or in art, it was not long until the exquisite forms which his patience and skill extricated from the rocky matrix contributed to the most pleasurable esthetic enjoyment.

To a mind as gifted as Wachsmuth's the more purely intellectual questions of morphology, derivation, and natural relationships became invested with the keenest interest, and soon the collection and study of crinoids was pursued with an ardor amounting almost to a passion. From Burlington his interest in the subject extended until it comprehended the crinoids, past and present, of the world. The success of his life-work may be measured by the fact that long before his death Charles Wachsmuth was the acknowledged authority the world over in his special line of paleontologic investigation.

The story of his life is easily told. Charles Wachsmuth was born on the 13th day of September, 1829. He was a native of Hanover, Germany, from which place he came to America as the agent of a German emigration company in 1852. He spent two years in New York city, and then, in the hope of finding a climate more suitable to the condition of his health, he removed to Burlington, Iowa. At Burlington he entered into business on his own account; here, too, he was married. His union in 1855 to Miss Bernandina Lorenz was one of those felicitous events that profoundly affected his life and insured the success of the work to which his future years were to be devoted. Domestic peace, loving and ever vigilant care for his health and comfort, companionship in his rambles and more extended journeys in quest of specimens, enthusiastic encouragement and energetic helpfulness in all his work, whether in field or study, these were the blessings that this devoted wife brought to her husband. The world of science owes a large debt to Mrs. Wachsmuth.

The Wachsmuth collection of crinoids was first brought prominently to the attention of paleontologists by the publication of volumes II, III, and V of the "Geology of Illinois." A very large proportion of the species of crinoids described by Meek and Worthen in the volumes mentioned had been collected, freed from the matrix, critically studied, and their taxonomic relations determined by the zealous but unobtrusive paleontologist of Burlington.

In 1865 Mr Wachsmuth closed out his business and thenceforth devoted his entire energies to work on crinoids. The large size and rare beauty of his collection attracted the notice of Professor Agassiz in 1873. Soon the collection was bought outright, and Wachsmuth was engaged to go with it as curator of crinoids in the Museum of Comparative Zoology at Cambridge. His connection with the museum, which terminated with the death of his revered friend, gave him enlarged opportunities for study in his favorite field, so that when he returned to Burlington, after an extensive tour of Europe and the Orient, Wachsmuth took up the study of crinoids with even greater ardor than before. About this time Mr Wachsmuth found in Mr Frank Springer, then a young attorney of Burlington, a collector of crinoids quite as enthusiastic as himself. Common interests and common tastes brought these men together, and acquintance soon developed into friendship. Since then, until the death of the senior put an end to the happy association, the energies of both were devoted to a single end, and the collections grew and embraced the crinoids of every region and of all geologic time. The literature of the subject also was collected until every important publication relating to the special subject of study found a place on the shelves of their working library. It was with the preparation and equipment above indicated that Wachsmuth and Springer began to publish the results of their investigations. The most important works by these two authors are the "Revision of the Paleocrinoidea," published by the Philadelphia Academy of Natural Science, between 1879 and 1886, and the superb "Monograph of the Crinoidea Camerata of North America," published by the Museum of Comparative Zoology.

The complete list of titles compiled by Dr Keyes* is as follows :

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Crotalocrinus: its structure and zoological position: *Ibid.*, pp. 364–390.

Perisomic plates of the crinoids: *Ibid.*, 1890, pp. 345–392.

New species of crinoids and blastoids from the Kinderhook group of Le Grande, Iowa: *Illinois Geol. Survey*, vol. 8, 1890, pp. 157–251.

Description of two new genera and eight species of camerate crinoids from the Niagara group: *Am. Geologist*, vol. 10, 1892, pp. 135–144.

Monograph of the Crinoidea Camerata of North America: *Memoirs of Museum of Comparative Zoology*, 2 vols., 1895, 800 pp., and atlas of 83 plates, comprising 1,500 illustrations.

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*American Geologist, vol. xvii, March, 1896, p. 136.

The following memorial was read by F. D. Adams in the absence of the author.*

MEMOIR OF N. J. GIROUX

BY R. W. ELLS

It is with feelings of very deep regret that we have to announce the somewhat sudden death of one of our members, Mr N. J. Giroux, of the Canadian Geological Survey, Ottawa, which occurred at his father's house in River Beaudette, province of Quebec, on the 30th day of November, 1896. Mr Giroux was held in high esteem by all his confreres on the staff, and aside from the general feeling of regret at his unexpected death, his loss at this time is especially unfortunate, since the results of his last two years' work in the interesting area between the lower Ottawa and the Saint Lawrence, in the study of which he has recently been engaged, were nearly ready for publication and would have made a very valuable contribution to our knowledge of this interesting field, both as regards the distribution and the fossil contents of the Paleozoic formations of the Ottawa basin.

Mr Giroux was born at River Beaudette on October 22, 1859. He graduated from L'Ecole Polytechnique, Montreal, in affiliation with Laval University, in 1880, taking the degree of C. E. from that institution and the gold medal for standing in his year. After a year in the northwest territories, in connection with the Dominion Lands Survey, he was engaged as assistant engineer on the Grenville canal, leaving that work in 1883 to join the staff of the Geological Survey of Canada as assistant to Dr Ells. In this capacity he did much excellent work for some years, and in 1890 took charge of surveys in the rough country north of the Saint Lawrence, in the vicinity of the Saint Maurice waters. After three years in this arduous field, he took charge of his last field of work, to the south of the lower Ottawa river, which he was rapidly bringing to completion when his labors were cut short by his death.

Mr Giroux's principal publications have appeared in his summary reports of progress, which are issued in connection with the annual reports of the Geological Survey. The five volumes, 1891–1897, contain his writings. Among other papers is one on the serpentines of Canada in the Transactions of the Ottawa Naturalist; but he had laid well the foundations for an active and useful life, which would doubtless have been productive of valuable results to the scientific world, and his death is therefore regarded as a very serious loss to the field staff of the Geological Survey of Canada.

*The memorial was read on Wednesday morning, as Dr Adams was not present when it was reached in regular order Tuesday morning, but it is inserted here in its appropriate place.

The presentation of scientific papers was declared in order under the customary rules. The first paper read was presented by the author, with the aid of lantern views.

CRATER LAKE

BY J. S. DILLER

The paper was discussed by the President and Messrs H. F. Reid, N. S. Shaler, H. W. Turner, and the author. The paper is published in the National Geographic Magazine, volume viii, February, 1897, pages 33–48.

The second paper was also illustrated by lantern views and read by the author.

THE LEUCITE HILLS OF WYOMING

BY J. F. KEMP

Remarks were made by C. W. Cross. The paper is printed as pages 169–182 of this volume.

The next paper was entitled—

SOLUTION OF SILICA UNDER ATMOSPHERIC CONDITIONS

BY C. WILLARD HAYES

Remarks were made by J. F. Kemp, G. K. Gilbert, N. S. Shaler, B. K. Emerson, J. J. Stevenson, I. C. White, and M. R. Campbell. The paper is printed as pages 213–220 of this volume.

Following the discussion of this paper the meeting was adjourned for lunch.

The Society reconvened at 2 o'clock p m, and the first paper was read as follows:

EROSION AT BASELEVEL

BY M. R. CAMPBELL

Remarks were made by J. P. Iddings, C. W. Hayes, M. E. Wadsworth, H. W. Turner, and the President. The paper is printed as pages 221–226 of this volume.

The next paper was by the same author:

THE ORIGIN OF CERTAIN TOPOGRAPHIC FORMS

BY M. R. CAMPBELL

Remarks were made by Arthur Keith. An abstract of the paper is published in Science, volume v, January 15, 1897, pages 83, 84.

The next paper, illustrated with lantern views, was entitled—

HOMOLOGY OF JOINTS AND ARTIFICIAL FRACTURES

BY J. B. WOODWORTH

A brief abstract is published in the Journal of Geology, volume v, January–February, 1897, pages 97, 98.

The following paper was also illustrated by lantern views:

PHYSIOGRAPHIC DEVELOPMENT OF THE DISTRICT OF COLUMBIA REGION

BY N. H. DARTON

The next paper, by the same author, was entitled—

DIKES IN APPALACHIAN VIRGINIA

BY N. H. DARTON

Remarks were made by J. J. Stevenson.

The following paper was then read:

ON THE CHANGES OF DRAINAGE IN THE OHIO RIVER BASIN

BY FRANK LEVERETT

The paper was discussed by the President, G. F. Wright, M. R. Campbell, Edward Orton, N. S. Shaler, I. C. White, H. P. Cushing, and the author.

An abstract of this paper is published in Science, vol. v, January 15, 1897, page 85.

Mr S. F. Emmons made some announcements, and the Society adjourned until the evening session.

Session of Tuesday Evening, December 29

The evening session was held in the lecture hall of Columbian University for the presentation of the Presidential address. Mr G. K. Gilbert introduced President Le Conte, who delivered his address, entitled—

EARTH-CRUST MOVEMENTS AND THEIR CAUSES

BY THE PRESIDENT, JOSEPH LE CONTE

It is printed as pages 113–126 of this volume.

Session of Wednesday, December 30

The Society convened at 10 o'clock a m, President Le Conte in the chair.

The report of the Council was taken from the table and adopted without debate.

The memoir of N. J. Giroux was read by F. D. Adams at this time, but is inserted in proceedings of the preceding day (see page 377).

The following report of the Photograph Committee was read by George P. Merrill, the chairman of the Committee:

SEVENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

To the Council of the Geological Society of America:

The Committee on Photographs have to report the addition of 139 views, bringing the full number in the collection up to 1,421. The donors, named in the order of their sending, are: U. S. Geological Survey (Bailey Willis, 28); U. S. Geological Survey (G. K. Gilbert, 13); U. S. Geological Survey (Whitman Cross, 12); J. P. Bishop, Buffalo, New York (17); Professor Horace B. Patton, Golden, Colorado (5); Professor Frank Adams, Montreal, Canada (10); U. S. National Museum (George P. Merrill, 20); Professor J. F. Kemp (34).

The chairman wishes once more to call the attention of the members to the fact that the work of the committee is being done almost wholly in the dark. They have no means of knowing how far the collections meet the wants of the members, or how much demand there may be for prints. During the entire year the chairman has not received a single unsolicited suggestion. Under these circumstances he feels that if the collection is lacking in desirable materials the committee should not be held responsible.

It may be well further to call the attention of the Society to the fact that with the lapse of years many of the negatives from which these prints are made are likely to become lost, mislaid, or broken. This is particularly true of those belonging to private individuals. The advisability of securing such negatives for the Society is therefore one that might well receive consideration at this time.

Respectfully submitted.

George P. Merrill,
Chairman.

Washington, D. C., *December 29, 1896.*

REGISTER OF PHOTOGRAPHS RECEIVED IN 1896

Twenty-eight views presented by the U. S. Geological Survey (Bailey Willis)

Size, 6 by 8 inches. Figures in parentheses are original numbers

1283 (3). Crater lake, Mount Rainier, Washington; elevation 5,200 feet. View of a lake on the northwest slope of Mount Ranier, having a diameter of about half a mile. It is probably a large crater. The rocks are glaciated and their rounded form is shown in the point extending from the group of trees on the right down to the lake.

1284 (5). North Puyallup glacier, Mount Rainier, from Eagle Cliff. General view from same point as number 6, showing the Puyallup canyon, about 2,000 feet deep, and the Puyallup glacier in the distance.

1285 (6). North Puyallup glacier, Mount Rainier, from Eagle Cliff. General view of the northwestern slope, comprising the Puyallup glacier and the Liberty Cap; elevation 14,000 feet. The head of the glacier in the hollow on the left is about four miles away, at an elevation of 10,000 feet. The terminus of the glacier, consisting of two fan-like tongues, is lost in the lower right-hand corner of the picture in the fog.

1286 (7). Liberty Cap from near Spray falls, Mount Rainier. Detailed view of the northwestern slope, showing the central portion of the Puyallup glacier and the precipitous slopes of the Liberty Cap, which rises 3,500 to 4,000 feet above it.

1287 (9). Evening on the northwestern slope of Mount Rainier. View of the snow-fields, with a group of krummholtz in the foreground; elevation about 7,000 feet. The summit of Mount Rainier is about four miles distant, and the intervening snow-fields are broken by crops of andesitic lavas and scoriæ. The solid rock surfaces are extensively glaciated.

1288 (10). Northwestern slope from 10,000 feet, Mount Rainier. View of the head of the Puyallup glacier and the Liberty Cap, showing details of crevasses and the distribution of snow in August, 1895.

1289 (14). Carbon River glacier, Mount Rainier. View from the eastern lateral moraine of the Carbon River glacier, showing the sweep of the ice as it descends from beneath the great northern amphitheater of Mount Rainier. In the foreground the slope of the lateral moraine toward the glacier shows how extensively it has lost in volume, and the ice is covered with morainal material.

1290 (15). Flora east of Carbon River glacier, Mount Rainier. August flora on the edge of the Carbon River glacier.

1291 (17). Ice cascades, head of Carbon river, Mount Rainier. View in the great amphitheater, the gathering point of the Carbon River glacier. On the left of the picture the cliffs rise 6,000 feet to the Liberty Cap and the glacier flows out to the right (see number 14).

1292 (21). Jointed granite, Denny creek, Snoqualmie, Washington. Glacial amphitheater eroded in the granite. The streams of this portion of the Cascade range descend by a series of steps, each of which is attributed to the retrogressive work of glacial action (see number 25).

1293 (23). Falls on upper Snoqualmie river. View of falls and canyon in metamorphosed grits and slates of Miocene age near the summit of the Cascade range, Snoqualmie pass; elevation 3,000 feet.

1294 (25). Falls on Snoqualmie river. Franklin falls about two miles west of Snoqualmie pass.

1295 (34). The Needles from Poodledog pass, Monte Cristo, Washington. The Needles (see number 38) are composed of breccia from Twin Lake crater, off to the right. An important mineral vein is the cause of the ravine between them.

1296 (37). Pride of the Mountain range, Monte Cristo. This range lies east of Monte Cristo, separating that district from the Goat Lake district. A portion of the high peaks consists of diorite, and they are traversed by numerous metalliferous veins. Their elevation is 6,500 to 7,000 feet.

1297 (38). Panorama from Willmann pass (north half), Monte Cristo. The divide between Silver creek, flowing south, and Sauk river, flowing north, at Willmann pass is an arête with an elevation of 4,800 feet. We stand on its crest, looking northeast. Monte Cristo, the mining camp, lies in the canyon in front of the farther range. The Needles and Willmann peak, composed of breccia from Twin Lake crater, rise in the right of the picture (see continuation in 39).

1298 (39). Panorama from Willmann pass (south half), Monte Cristo. The foreground shows the descent into the "'76" amphitheater leading to Monte Cristo. The high peak in the center is Glacier peak, on the right of which, in the basin 2,500 feet deep, lie Twin lakes. A small glacier extends northward from the peak. The district produces argentiferous and auriferous sulphurets.

1299 (40). Glacier peak, Monte Cristo. View from the same point as number 39; taken with a narrow angle lens to show details of Glacier peak.

1300 (41). Glacier peak from Goat peak, Monte Cristo. We stand on the ridge between the crater basin of Twin lakes on the right and the glacial amphitheater leading down to Monte Cristo on the left, looking east. The rocks in the foreground are granite. The mass of Glacier peak, including the near high ridge, is composed of volcanic breccia. The contact between the two occurs along a vertical plane immediately at the foot of the first ascent from the foreground (see 52). The flows from Twin Lake crater are distinctly bedded and dip eastward (see 43).

1301 (43). Cliffs of porphyrite and breccia, Glacier peak, Washington. View from the same point as 41; taken with a narrow angle lens to show details of bedded and vertical structure in flows from Twin Lake crater.

1302 (45). Looking west from Goat peak, Monte Cristo. View of Silver Lake and Silver Tip mountain a mile and a half southwest of Monte Cristo, Washington. The rock of the vicinity is a massive volcanic. The lake occupies a basin, which is presumably a crater, but which may possibly belong to the class of hollows produced by retrogressive glacial erosion. Attention is called to the extremely abrupt peaks characteristic of this portion of the Cascade range.

1303 (46). Silver lake, Monte Cristo (see 45). Near view of Silver lake, showing the outlet and the surrounding cliffs of porphyrite.

1304 (49). Looking down Twin lakes, Monte Cristo. General view of Twin lakes about three miles southeast of Monte Cristo. These lakes occupy basins of craters, the largest being about half a mile in length. The rock surrounding them in the foreground, on the right of the picture, is granite, while much of the farther side of the lake and the foreground in the extreme left is volcanic breccia. Spherulitic rhyolite occurs at the east end. The higher cliffs in the vicinity are largely made up of breccia with granite fragments. The foreground exhibits *roches moutonnées*.

1305 (51). Upper Twin lake from the east end, Monte Cristo (see 49). View from the east end of upper Twin lake. The cliff on the right is granite, while the talus in the foreground is composed of blocks of volcanic breccia. Immediately behind the camera, cliffs of breccia rise about 2,500 feet to the summit of Glacier peak (see 41 and 43).

1306 (52). Volcanic breccia of Twin Lake crater, Monte Cristo (see number 41). The camera stands on the arête between Twin lakes and the "'76" amphitheater, looking into the latter. The breccia on the right was erupted from Twin lakes, and is in immediate contact with the granite, of which it contains fragments.

1307 (54). Sauk mountain from near Sauk, Washington. It rises abruptly on the western bank of the Skagit river. It is an old volcanic vent, probably represented by a lake which now lies in a deep basin near the summit. The elevation is about 5,800 feet, and the volcanics are erupted through a mass of iron-bearing schist and limestone.

1308 (60). Landslide crack, Sauk mountain. On the left of the view the descent is precipitous for 500 or 600 feet. The crack in the middle ground on the right is evidently due to an outward movement of the rock mass toward the cliff, but is now filled with debris to within a few feet of the top.

1309 (63). Limestone, Baker River canyon, Washington. View on Baker river half a mile above its junction with the Skagit. The river flows through a canyon which it enters from a broader valley carved in shales. The rocks of the canyon are a highly crystalline limestone dipping northwest. Crinoids have been discovered and other fossils may be expected. These are the oldest known rocks in Washington.

1310 (65). Salmon fishing and limestone, Baker River canyon, Washington (see 63). View looking down Baker River canyon toward the Skagit. The masses of limestone in the foreground are among those in which crinoids were found. The high stage of the river has forced the salmon into the eddies among the boulders, and the fisherman, taking advantage of their position, is able to catch them at will.

Thirteen views presented by the U. S. Geological Survey (G. K. Gilbert)

Size, 4½ by 7½ inches. Figures in parentheses are original negative numbers

1311 (35). Group of Tepee buttes north of Nepesta, Pueblo county, Colorado.

1312 (30). Tepee butte; core not exposed; two miles northeast of Boone, Colorado.
1313 (37). Exposed core of a Tepee butte north of Nepesta, Colorado.
1314 (24). The Great Plains. Characteristic landscape on broad upland between the Platte and Arkansas rivers, Colorado.
1315 (26). The Great Plains, Colorado. Spring issuing from the "Tertiary grit" (Hay) irrigates a few acres and affords water for cattle.
1316 (83). Haystack butte, Pueblo county, Colorado. A typical mesa butte. Geologically an outlier of the Niobrara limestone protecting upper Benton shales. Lakelet basin in foreground, hollowed by wind erosion.
1317 (41). End view of South Rattlesnake butte, an outlier of Niobrara limestone, Huerfano county, Colorado.
1318 (24). Side view of North Rattlesnake butte, Huerfano county, Colorado. A remnant of Niobrara limestone capping a pyramid of upper Benton shale. The trees are juniper from 10 to 12 feet high.
1319 (73). Typical water-pocket near Thatcher, Colorado. Timpas creek has here made a canyon 50 feet deep in Dakota sandstone.
1320 (67). The Greenhorn formation, Middle Benton, exposed in an arroyo near Thatcher, Colorado. The upland at the right is capped by Niobrara limestone. The formation consists of a rapid alternation of limestone and shale, indicating a rhythm in the conditions of sedimentation.
1321 (50). A cliff determined by a fault, Las Animas county, Colorado. The hard rock at the right is Dakota sandstone, originally covered by Benton shale. The plain at the left consists of Benton shale underlain by Dakota sandstone. The fault line follows base of cliff, and the block at the left stands about 200 feet lower than the block at the right. The country has been greatly degraded since the faulting, and the cliff results immediately from the unequal erosion of soft shale and hard sandstone.
1322 (13). Modern rain-prints, natural size. Dried mud from Great Plains, Colorado. Animal tracks also shown.
1323 (100). Ant hill, Pueblo, Colorado.

Twelve views presented by the U. S. Geological Survey (*Whitman Cross*)

Size, 8 by 10 inches. Figures in parentheses are original numbers

1324 (1). Eastern part of San Miguel mountains, Colorado. The sharp peak of mount Wilson (14,000 feet) is of diorite cutting up through Cretaceous and Eocene strata.
1325 (7). Mount Wilson group. San Miguel mountains, Colorado. The smooth slopes of middle ground are of Cretaceous shales. The canyon in foreground is cut below the Dakota sandstone.
1326 (8). Western portion of San Miguel mountains, Colorado. The sharper points are denuded laccoliths in Cretaceous shales. The plateau seen extends westward into Utah.

1327 (9). Mountains north of the San Miguel river near Telluride, Colorado. The lighter colored band of strata belong to an Eocene (?) conglomerate. Above it 2,500 feet of andesitic tuff and bedded breccia. Forms panorama with number 10.

1328 (10). Mountains north of the San Miguel river near Telluride, Colorado. Dallas peak (13,700 feet). Forms panorama with number 9.

1329 (15). Mount Sneffels, San Juan mountains, Colorado (14,000 feet). A great diorite and gabbro mass cutting up through andesitic tuffs and breccias. Tertiary.

1330 (28). A characteristic cliff of fine grained andesitic tuff. Bridal Veil basin, near Telluride, Colorado.

1331 (31). South Lookout peak near Ophir, San Juan mountains, Colorado. Characteristic cliffs and pinnacles of coarse, bedded, andesitic breccia and tuff.

1332 (35). Iron spring near Ophir, Colorado. The spring has built up a terrace of reddish, sinter-like materials, as about the Yellowstone hot springs.

1333 (40). The Twin Sisters peaks, San Juan mountains, Colorado. Jurassic strata form smooth slopes of middle ground; an Eocene (?) conglomerate, the cliff next above; Tertiary tuffs the peaks proper. Forms panorama with number 41.

1334 (41). East of Twin Sisters peaks (forming panorama with number 40). Triassic conglomerate causes cliffs of foreground. Eocene (?) conglomerate lies unconformably on Cretaceous, Jurassic, and Triassic strata on further side of central valley.

1335 (48). Vermillion peak, San Juan mountains, Colorado (13,700 feet). Typical cliffs of bedded breccias and tuffs. Rhyolite flows cause summit cliffs.

Seventeen views photographed and presented by J. P. Bishop, 109 Norwood Avenue, Buffalo, New York

Size, 4½ by 7½ inches

1336. Setting-tank for brine, Kerr salt works, Rock Glen, New York.
1337. Works of Warsaw Salt Company, Warsaw, New York.
1338. Salt pan, Genesee salt works, Biffard, New York.
1339. Kettles with steam jacket, Standard works, Warsaw, New York.
1340. Grainer process, Perry salt works, Perry, New York.
1341. Barreling salt, Castile, New York.
1342. Bagging salt, Castile, New York.
1343. Group of salt packers, Castile, New York.
1344. Bucket for hoisting. Salt mine, Griegsville, New York.
1345. Breaker, Retsof salt mine, Griegsville, New York.
1346. Pile of salt "culm," Retsof mine, Griegsville, New York.
1347. Exterior of salt-block, Syracuse, New York.
1348. Interior of same showing kettles.
1349. Solar salt works, Syracuse, New York.
1350. Draining salt, Solar salt works, Syracuse, New York.
1351. Carting salt, Solar salt works, Syracuse, New York.
1352. Deserted salt works, Syracuse, New York.

Five views presented by Horace B. Patton, Golden, Colorado

Size, 6 by 8. Original numbers in parentheses

1353 (219). Effects of rain erosion on horizontally bedded andesite conglomerate. Headwaters of Rio Grande river, Colorado.

1354 (222). Effects of rain erosion on horizontally bedded andesite conglomerate. Headwaters of Rio Grande, Colorado.

1355 (223). Effects of rain erosion on horizontally bedded andesite conglomerate. Headwaters of Rio Grande, Colorado.

1356 (225). Effects of rain erosion on horizontally bedded andesite conglomerate. Headwaters of Rio Grande, Colorado.

1357 (226). Effects of rain erosion on horizontally bedded andesite conglomerate. Headwaters of Rio Grande, Colorado.

Ten views photographed and presented by Professor Frank D. Adams, Montreal, Canada

Size, 4 by 5 inches

1358. Embankment of river Po, near Ponte Lago Scuro. Right bank. From the plain, looking west.

1359. Embankment of river Po, near Ponte Lago Scuro. Right bank. From same point as number 1, looking east.

1360. General view of embankment, taken from point half way up its side, with Ponte Lago Scuro and railway bridge in distance.. Shows the three terraces of the embankment.

1361. View across the Po from summit of embankment on south side. Buildings of S. M. Maddalena on northern side partially hidden behind the embankment in front of them.

1362. View of the Po from summit of embankment on south side. Sand bar in the river.

1363. Right bank of Po from bridge of boats in the middle of the river, 7 feet above the level of the water. Buildings of Ponte Lago Scuro partially hidden behind embankment.

1364. Left bank of Po from same point of view as number 6. Three terraces of embankment well seen; lowest terrace cut into by the river.

1365. Railway bridge which crosses the river a short distance to the east of the bridge of boats; taken from the latter.

1366. Walls of Ferrara from the Lombard plain, 6½ feet above sealevel, with leaning tower of San Benedetto appearing above them.

1367. View of the Lombard plain between Ferrara and river Po.

Twenty views presented by the U. S. National Museum (George P. Merrill)

Size, 6½ by 8½ inches

1368. The Bartlett boulder. A glacial-drift boulder at Bartlett, New Hampshire. This boulder is of the Conway granite, and rests on four smaller boulders of the same kind on the summit of a knoll of till projecting through the modified till.

1369. The Washington boulder, Conway, New Hampshire.

1370. The Washington boulder. A glacial-drift boulder at Conway, New Hampshire. This is a very solid block of Conway granite. It cannot be shown to have been transported more than one mile. Its dimensions are 30 by 40 by 25 feet. View from the northeast.
1371. Cathedral rock. Profile view from the northeast. North Conway, New Hampshire. The hills show the typical *roche moutonnée* outline.
1372. Marine erosion of till, Boston harbor.
1373. Marine erosion of till, Long Island head, Boston harbor.
1374. *Roche moutonnée*, Marblehead, Massachusetts.
1375. Ship rock, Massachusetts. A glacial-drift boulder at Peabody. This boulder is 51 feet long, 27 feet wide, and 31 feet high. View from the north. The source is probably local.
1376. Churchill rock, Nottingham, New Hampshire. A glacial-drift boulder on Pawtuckaway mountain. This boulder is 62 feet long, 40 feet wide, and 40 feet high; estimated to contain 75,000 cubic feet and weighs 6,000 tons. The source is probably local. View from the southwest.
1377. Marine erosion of till, Boston harbor. Cliff on eastern edge of Great Brewster islands (a drumlin).
1378. Glacial-drift boulders, Rattlesnake island, lake Winnepesaukee, New Hampshire.
1379. Hypothetical map of the North American continent during the period of maximum glaciation, in early Pleistocene time.
1380. Hypothetical map of the North American continent at the close of Neocene time.
1381. Hypothetical map of the North American continent in Middle Cretaceous time.
1382. Hypothetical map of the North American continent at the close of Carboniferous time.
1383. Hypothetical map of the North American continent in early Carboniferous time.
1384. Hypothetical map of the North American continent in early Devonian time.
1385. Hypothetical map of the North American continent in earliest Silurian time.
1386. Hypothetical map of the North American continent in early Lower Cambrian time.
1387. Hypothetical map of the North American continent during late Algonkian time.

Thirty-four views presented by J. F. Kemp

The Minnesota views were taken during the summer of 1894; all others in the summer of 1896. Size, 4½ by 6½ inches

1388. Open cut at iron mines of the Minnesota company. Tower mine, showing forking of beds, Vermillion Lake district.
1389. Open cut at iron mines of the Minnesota company near Tower, Minnesota.
1390. Sunken ground over the Chandler mine, Ely, Minnesota.
1391. Sunken ground over the Chandler mine, Ely, Minnesota.
1392. Auburn mine near Virginia, Minnesota, stripped ready for mining.

1393. Oliver mine, Virginia, Minnesota; entering cut, upper bench gravel, lower bench ore.
1394. Oliver mine, Virginia, Minnesota; west cut, stripped ready to mine.
1395. Working face of the Mountain iron mine, Minnesota.
1396. Working face of the Mountain iron mine, Minnesota; broadside view.
1397. Working face of the Mountain iron mine, Minnesota.
1398. Surface panorama of Canton mine, Mesabi range, Minnesota.
1399. Caved surface of Canton mine, Mesabi range, Minnesota.
1400. Open cut in Father de Smet mine, Black hills of Dakota.
1401. Old Abe cut, Lead City, Black hills.
1402. Deadwood cut, with cap of porphyry, Lead City, Black hills.
1403. Golden Star cut, Highland shaft in background, Lead City, Black hills, 1896.
1404. Terra cut, Lead City, Black hills.
1405. Lead City from Highland shaft, Black hills.
1406. Terrys peak and town of Terry, Black hills.
1407. Bear butte from Plain to South Black hills, a trachyte plug.
1408. Plains from south foot of Bear butte, Black hills.
1409. Deadwood gulch, near Deadwood, Black hills. The near cliffs are phonolite.
1410. Contact of basic granite (left side) and acid granite (Bluebird granite) intended in former cut on Butte, Anaconda and Pacific railroad, Butte, Montana.
1411. Butte; the Parrot and Anaconda mines, Montana, with bounding ranges on east.
1412. The Lexington mine, Butte, Montana.
1413. Rhyolite butte, at Butte, Montana, from southeast.
1414. View into Idaho from Montana, Idaho line, summit of the Rocky mountains northwest of Red Rock, Montana. The mountains are chiefly pre-Cambrian quartzite.
1415. Terraces of Tertiary lake-beds, near Salmon City, Idaho, on the Lemhi river.
1416. Terraces of Tertiary lake-beds, on Lemhi river, near Salmon City, Idaho.
1417. Old gold diggings, on Napias creek, Leesburg, Idaho, worked 1859 to 1865.
1418. Hydraulic mining at California bar, Idaho.
1419. Rocky cut for sluice, California bar, Idaho.
1420. Discharge sluice, California bar, Idaho.
1421. Boulder clay; new site of Columbia University, New York.

The suggestions of the report relating to discrimination in acceptance of material and the ownership of negatives led to some debate, with opinions both for and against the latter proposition. No action was taken upon the suggestions, but the report as a whole was adopted, and the annual appropriation of $15 was continued for 1897.

Mr Arnold Hague submitted a written report of the Auditing Committee, stating that an examination of the Treasurer's accounts for the past fiscal year showed them to be correct and as stated in the printed report of the Treasurer. The report of the committee was adopted.

The Secretary announced proposed changes in the Constitution as follows:

To insert in Article IV, Section 1, the words "an Editor," thereby making the Editor an *ex-officio* member of the Council; also revising Article IV, Section 6, so that it shall read: "6. The Editor shall supervise all matters connected with the publications of the transactions of the Society, under the direction of the Council."

Mr S. F. Emmons announced that the Fellows were invited to make an inspection of the new Congressional Library building at 9 o'clock Friday morning; also that the customary subscription dinner would be held at the Hotel Raleigh this evening.

After some announcements by the Secretary regarding the business of the meeting, the scientific program was resumed, and the first paper read was—

NOTES ON THE STRUCTURE OF THE CRANBERRY DISTRICT IN NORTH CAROLINA

BY ARTHUR KEITH

A brief abstract is published in Science, volume v, January 15, 1897, page 86.

The second paper was—

NOTE ON THE STRATIGRAPHY OF CERTAIN HOMOGENEOUS ROCKS

BY C. H. HITCHCOCK

[*Abstract*]

Because of the attention recently given to studies of foliation and cleavage in homogeneous rocks I have searched anew for phenomena illustrative of them in the Connecticut valley with some success. In the report upon the geology of Vermont (1861) I described the admirable illustrations of original and superinduced planes in the "Talcose conglomerate" of Richmond and Fairfax (pages 389, 390). This terrane seems to correspond with what Mr C. L. Whittle has called the "Mendon series,"* in which the distinctions between two sets of planes is very obvious.

I have now found both cleavage and stratification planes in three ranges of homogeneous rocks farther east, where they have not been before observed. In the argillite extending southwardly from lake Memphremagog past Montpelier these different planes appear, notably in the slate quarries of Northfield. Farther east equally satisfactory illustrations occur in Thetford and vicinity. The strata planes dip westerly at a small angle, while the cleavage dips 50 degrees easterly.

* Journal of Geology, vol. ii, p. 396.

Similar planes appear in the micaceous quartzite, just to the west, which underlies the more calcareous division of the "calciferous mica-schist," and thus it is plain that the Thetford argillite is older than the mica-schist.

Last of all, other illustrations appear in Hanover and Lebanon, New Hampshire, in the "Coös quartzite," a rock lithologically like the Lower Cambrian quartzite on the west flank of the Green mountains.

We can therefore say that the majority of the so-called strata dips of these rocks are cleavage planes, and that the original structure has been commonly obliterated. The importance of these discoveries consists in the confidence given to our belief in this obliteration of the strata. So long as it was uncertain what the truth might be, it was difficult to be satisfied with the sections protracted.

It is worthy of note that the revision of the dips has thus far not affected our expressed conclusions respecting the relative ages of the several terranes of the district.

Remarks were made by A. C. Lane. A brief abstract is published in Science, volume 5, January 15, 1897, p. 86.

The third paper was entitled—

UNCONFORMITIES OF MARTHAS VINEYARD AND OF ROCK ISLAND

BY J. B. WOODWORTH

Remarks were made by W. B. Clark, David White, and G. K. Gilbert. The paper is printed as pages 197–212 of this volume.

In the absence of the author, the next paper was presented in abstract by Mr Gilbert, its place in the program being held by special vote:

CEMENTING MATERIALS OF THE TERTIARY SANDS AND GRAVELS OF WESTERN KANSAS

BY ERASMUS HAWORTH

A discussion of this same subject, but in a different form, is given in volume II of the University Geological Survey of Kansas.

The following paper was then read:

THE WORK OF THE UNITED STATES GEOLOGICAL SURVEY IN THE SIERRA NEVADA

BY H. W. TURNER

Remarks were made by the President, J. E. Wolff, C. D. Walcott, and the author.

The next paper was read by title:

GEOMORPHY OF JAMAICA AS EVIDENCE OF CHANGES OF LEVEL

BY J. W. SPENCER

The last paper of the morning session was—

FORMER EXTENSION OF CORNELL GLACIER NEAR THE SOUTHERN END OF MELVILLE BAY

BY RALPH S. TARR

Remarks were made by G. F. Wright and Angelo Heilprin. The paper is printed as pages 251–268 of this volume.

Following this paper an adjournment was taken for lunch.

The Society reconvened at 2 o'clock p m. The first two papers were discussed as a unit:

LAKE WARREN SHORELINES IN WESTERN NEW YORK AND THE GENEVA BEACH

BY H. L. FAIRCHILD

This paper is printed as pages 269–284 of this volume. A brief abstract is published in the Journal of Geology, volume v, 1897.

OLD TRACKS OF ERIAN DRAINAGE IN WESTERN NEW YORK

BY G. K. GILBERT

An abstract of this paper is printed as pages 285–286 of this volume.

Remarks upon the two papers were made by G. F. Wright, R. S. Tarr, F. B. Taylor, Frank Leverett, and the authors.

The next paper was—

THE ASSUMED GLACIATION OF THE ATLAS MOUNTAINS OF AFRICA

BY ANGELO HEILPRIN

Remarks were made by the President. A brief abstract is published in Science, volume v, January 15, 1897, page 88.

The following paper was read:

THE RELATION OF AN ABANDONED RIVER CHANNEL IN EASTERN IOWA TO THE WESTERN EDGE OF THE ILLINOIS ICE-LOBE

BY FRANK LEVERETT

Remarks were made by several Fellows. A brief abstract is published in Science, volume v, January 15, 1897, page 89.

The next paper was entitled—

GLACIAL OBSERVATIONS IN THE UMANAK DISTRICT, GREENLAND

BY GEORGE H. BARTON

Remarks upon the paper were made by C. H. Hitchcock, H. F. Reid, and Angelo Heilprin. An abstract of this paper is published in the Journal of Geology, volume v, pages 89–92; also in Science, volume v, January 15, 1897, page 89. The full paper is to be printed in the Technology Quarterly.

The following paper was read:

THE NIPISSING-MATTAWA RIVER, THE OUTLET OF THE NIPISSING GREAT LAKES

BY F. B. TAYLOR

Remarks were made by G. F. Wright and G. K. Gilbert. An abstract is published in Science, volume v, January 15, 1897, page 90.

The next and last paper of the session was by the same author:

MORAINES OF RECESSION AND THEIR SIGNIFICANCE IN GLACIAL THEORY

BY F. B. TAYLOR

Remarks were made by G. K. Gilbert, Frank Leverett, G. F. Wright, H. S. Williams, Angelo Heilprin, the President, and the author. An abstract of the paper is published in Science, volume v, January 15, 1897, page 90.

The evening of this day was devoted to the annual dinner of the Society, which was held at the hotel Raleigh. In addition to the Fellows, several guests were present, including ladies.

Session of Thursday, December 31

The Society was called to order at 10.15 a m by Vice-President Edward Orton.

Professor George H. Barton presented orally a proposition to indorse Lieutenant R. E. Peary's plan of sending scientific parties upon an expe, dition to Greenland during the summer of 1897.

Remarks in approval were made by Angelo Heilprin, and the matter was then laid upon the table until 2 o'clock p m.

It was proposed that, in order to save time and secure the presentation of all the papers upon the program within this day, certain designated papers of a petrographic character should be read in a separate section, and it was so voted.

PROCEEDINGS OF THE PETROGRAPHIC SECTION

The members interested thereupon proceeded to the laboratory of Dr George P. Merrill, in the National Museum, and at 11.30 a m organized a petrographic section. Professor B. K. Emerson was made chairman and Mr H. W. Turner secretary.

The proceedings were opened by the reading of a paper entitled—

APORHYOLITE OF SOUTH MOUNTAIN, PENNSYLVANIA

BY FLORENCE BASCOM

Contents

Topographic Features of the Area

The extension of the Blue Ridge in Pennsylvania known as the South mountain lies a little to the east of the middle of the state and stretches in a crescent-shaped curve from the Maryland state line toward the Susquehanna. Twelve miles southeast of Harrisburg it is interrupted by the Susquehanna valley. The same belt of highland reappears at Reading and can be traced for many miles to the northeast, where it merges into the Highlands of New Jersey, which in turn become the Green mountains of Massachusetts and Vermont.

From the state line to Dillsburg Junction, the most northerly extremity of South mountain proper, is a distance of 40 miles, while the greatest width of the mountain is something over 10 miles. South mountain, as the map shows you, is not a continuous mountain range, but rather consists of a series of broken hills and ridges, separated by high plateau-like valleys. The elevations do not exceed 2,000 feet. Jacks mountain, Rocky ridge, Green ridge, and Piney mountain are some of the more prominent highlands.

Former and recent Investigations

Throughout the South Mountain district are abundantly exposed distinct and interesting rock types, whose character has already been announced.* In 1892 detailed mapping was accomplished in the southern portion of the district. Field-work was resumed for a brief season during the fall of 1896. At this time further illustrations of the structures peculiar to aporhyolites were secured, and these it is proposed to present to you today.

Petrographic Structures of the Aporhyolites

Rocky Ridge and Raccoon creeks, eroding the aporhyolites for a distance of five miles respectively, furnish a collecting ground for acid volcanic material unsurpassed in any other portion of South mountain. The highland forming the watershed between these two creeks supplies to the streams brilliantly colored specimens, showing lines of flow of peculiar delicacy and intricacy. The crumpling of a fluid layer moving in a more viscous layer and retarded by it is conspicuously observable in some specimens.

There also occur here compact bluish gray aporhyolites studded with spherulites of a uniform size (three-eighths of an inch in diameter) and a deep blue color. The rock is porphyritic, and the feldspar phenocrysts are scattered indiscriminately through spherulites and matrix, which are not easily separated mechanically. In the thin-section the spherulites show, under crossed nicols, the micropoikilitic structure, which merges into a narrow border of a granular quartz-feldspar mosaic, so similar to the crystallization of the groundmass as only to be distinguished by the rim of iron oxide separating spherulite and groundmass. Occasionally the spherulites are vesicular and bear tridymite spherulites on the walls of the vesicles, which are filled with quartz. The groundmass usually shows perlitic parting, obliterated under crossed nicols by a granular crystallization.

At approximately the same locality were found aporhyolites, in which the spherulites are from one-half to three-fourths of an inch in diameter and drop out very readily from the matrix in which they are imbedded. In this case the microscope shows no border of granular crystallization surrounding the spherulites. The groundmass and the spherulites are sharply separated by the presence in the latter of a pronounced micropoikilitic structure of a rather coarse grain. This was true of all the spherulites which were sectioned. Such occurrences as these of the micropoikilitic structure make it impossible to escape the conviction that this structure may be a secondary one, although it has been otherwise interpreted by Dr Clements in similar acid volcanics of the Michigamme district. In the South mountain aporhyolites the structure has occurred either as a replacement of a radiating crystallization, where it must be subsequent to the consolidation of the lava, or in a presumably devitrified groundmass, where it must also be subsequent to consolidation.

This structure is also found in some of the quartz-porphyries of South mountain, where its secondary origin is not so clearly proven. The occasional character of its occurrence, however, and the close association of the quartz-porphyries possess-

*G. H. Williams: Am. Jour. Sci, vol. xliv, 1892, pp. 482–496. Bulletin U. S. Geological Survey, no. 136.

ing the structure with the aporhyolites, both being portions of a single flow, led to the assignment of a like origin for the structure in both types of the South Mountain acid volcanics.

Comparison with other Aporhyolites

Harker, in a discussion of similar ancient lavas of the Bala series, describes a structure which seems to be the micropoikilitic and whose origin he considers a primary one. In order that the structure may be recognized, it will be necessary to quote from him at some length. He says:

"In ordinary light the groundmass (808, Craig-Cwm-Silyn I) has a microfelsitic appearance, but is closely studded with round or elliptic light spots about 0.02 inch in diameter, each marked out by a dusty looking border. On using polarized light it is seen that within these little areas the quartz and feldspar are more or less completely individualized, the former being in excess of the latter, and the whole of the quartz in one of these spots behaves as one crystal. When the structure is imperfectly developed, the spots are of rather irregular form, but in the best specimens (808) they are sharply defined and elliptic in outline, while the opaque looking dust, as if eliminated from the interior, forms a narrow, elliptic ring just within the margin of the spot. The structure just described seems from appearance to be an original one. It has no connection with spherulitic growth, but seems to be rather of the nature of an ophitic structure, the quartz enclosing in part the feldspathic constituent. This is well seen when, as is sometimes the case, the feldspar occurs in the form of minute microlites with a partial fluxion arrangement."*

The examination of thin-sections of specimens from the above locality reveals the character of the crystallization which Harker has thus accurately described. The structure which he discusses is the micropoikilitic of recent nomenclature. The oval spots, with a zonal arrangement of the border, formed of globulites of iron oxide and epidote, vividly recall the completely altered spherulites of some of the South Mountain aporhyolites. In the extreme stage of alteration (static) of an aporhyolite the spherulites are only indicated by oval areas outlined by iron oxide. The true character of the oval areas is only revealed by a study of intermediate stages of altered spherulites both in the thin-section and in the hand specimen. In the light of a comparative study of aporhyolites an adequate explanation of the "elliptic spots" seems to be that there was present in them originally a spherulitic crystallization. This radiating structure has been replaced, as in so many cases in the aporhyolites, by the micropoikilitic structure. If this explanation be correct, here again the micropoikilitic structure is not an "original" but a secondary one. Further examination of thin-sections shows that the acid members of the Bala volcanic series have every right to the appellation aporhyolite. The "contemporaneous veins" mentioned by Harker seem to be altered chain spherulites. Perlitic parting is conspicuous in ordinary light and is effaced in polarized light by granular crystallization. The same yielding of spherulitic centers to solution and the secondary deposition of silica noted in the South Mountain aporhyolites is observable in the Bala acid volcanics.

Near Caledonia Springs, in the South mountain, occurs a conspicuously porphyritic aporhyolite crowded with minute (one millimeter in diameter) red spherulites.

Aporhyolites showing chain spherulites in an unusual state of preservation have also been recently found in the region of Graeffenburg, Adams county. The spherulitic bands are from one to three centimeters wide and number sometimes ten to a foot. The resemblance to banding in obsidians due to the same cause is striking.

* Alfred Harker: The Bala Volcanic Series of Cærnarvonshire and Associated Rocks. 1890, pp. 22, 23.

Many specimens showing lithophysæ were collected. The lithophysæ range from one-eighth of an inch to an inch in diameter and crowd every spare inch of the rock surface. Sometimes the concentric spaces between the petals of the lithophysæ are filled with quartz and hematite, but often they are invested with beautiful radiating crystals of piedmontite.

In other localities the aporhyolites are more or less charged with piedmontite, but its occurrence in lithophysæ has not before been observed. In the thin-section a markedly concentric arrangement of structures is to be noted. The center of a lithophysæ is a quartz-feldspar mosaic similar to the crystallization of the groundmass and may contain phenocrysts of quartz or feldspar. This center is surrounded by a border of brilliant radiating crystals of piedmontite and granular quartz. Projecting into this area of secondary material and resting upon the inner wall of a zone formed of a quartz-feldspar mosaic are traces of crystals showing prismatic and pyramidal faces. The inner wall is studded with these crystals, which in most cases are only preserved in outline. In other cases the quartz or alkali feldspar substance is retained.

Surrounding the lithophysæ and separating it from the groundmass is a fourth zone showing spherulitic and micropoikilitic crystallization. These zones are not fixed in number and may be many or few. The radiating crystallization may be completely or partially replaced by the granular. The interlamellar or interzonal spaces are alike filled with quartz and piedmontite.

Conclusions

Such are the most instructive features of the material recently procured. They serve to further emphasize the characters which have already been described* as peculiar to the aporhyolite, namely, the occurrence of fluxion, spherulitic, lithophysal, and perlitic structures associated with a holocrystalline groundmass and indicating by their pressure the secondary character of that groundmass.

This material further substantiates the claim made for the secondary origin of the micropoikilitic structure in the aporhyolite of South mountain.

Finally, the material discloses a new occurrence for piedmontite.

It is hoped eventually to map all of the South Mountain region in detail. A preliminary survey of the area leads one to expect no new rock types and no aporhyolites showing original structures in a more perfect state of preservation than does the material which has just now been discussed.

The paper was illustrated by a map of South mountain and a suite of specimens showing the typical structures of the mineral.

It was discussed by A. C. Lane, who corroborated the interpretation of the micropoikilitic structure as secondary in acid volcanics in the Lake Superior region. J. P. Iddings remarked that the micropoikilitic structure was undoubtedly both a secondary and a primary structure. While its secondary character in the case of the aporhyolite seemed beyond question, its primary origin in some porphyrites was equally certain. Whitman Cross corroborated J. P. Iddings.

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* Bulletin U. S. Geological Survey, no. 14.

The second paper was entitled—

AGE OF THE WHITE LIMESTONE OF SUSSEX COUNTY, NEW JERSEY

BY J. E. WOLFF AND ALFRED H. BROOKS

[*Abstract*]

The paper first reviewed the work and opinions of previous observers, which have mainly tended to either of two views, namely, that the white limestone is of pre-Cambrian age or that it is identical with the Cambrian blue limestone of the region, the present crystalline condition being due to the action of igneous rocks, perhaps assisted by regional metamorphism. In that connection the authors expressed their debt to the previous work of F. L. Nason, which all who visit the region must appreciate, whether or not they agree with his conclusions.

A description was then given of the detailed work, on which the conclusions of the present paper rest, illustrated by maps, cross-sections, and specimens. The new features of these observations were first the evidence for several faults in the field, two of especial importance being along the line of contact of the white and blue limestone, and, second, the description of a new quarry in the white limestone at Franklin, where the overlying Cambrian arkose has filled a deep crevice in the white limestone, and contains large fragments of that rock and pieces of mica, feldspar, and quartz characteristic of the white limestone, granite, and associated rocks, affording absolute proof of the pre-Cambrian age of the white limestone, and also an explanation of the apparent interbedding of the two rocks observed elsewhere. The results were summarized as follows:

Where there is not faulting, the sandstone lies between the blue limestone and the white limestone or gneiss, and is everywhere derived from the gneiss, the granite, or the white limestone, containing fragments of all three rocks. The blue limestone and sandstone are unconformable in dip to the foliation of the other rocks except along fault lines. The strike may or may not coincide. The white limestone has generally the same strike and dip of foliation as that of the gneisses, and the pitch structure of the latter is conformable in direction and amount to the pitch of the ore bodies of the white limestone. The granite nowhere cuts the blue limestone or sandstone, but cuts the white limestone and gneisses indiscriminately. The sandstone has in one place distinctly filled a crevice in the white limestone from above, containing boulders of the limestone and fragments of the characteristic minerals of this and the other rocks. The apparent transitions between the two limestones are explained as the result of fault brecciation and shearing, the apparent interbedding of the white limestone with the quartzite, as the result of the filling of preexisting fissures or cavities in the white limestone, often complicated by faulting. Since the white limestone is an integral part of the gneissic formation and of contemporaneous formation, and the granite which is eruptive through both is of later origin, coming after the formation of the characteristic structures of foliation and pitch, it seems necessary to ascribe the present mineral composition of the limestone and ore bodies to causes not necessarily connected with the intrusion of the granite, however much that may have acted locally.

The paper was discussed by B. K. Emerson, J. F. Kemp, and J. E. Wolff.

At 12.45 p m the section adjourned for lunch.

Reconvening at 2 p m, the first paper, read by the senior author, was entitled—

ORIGIN AND RELATIONS OF THE GRENVILLE-HASTINGS SERIES OF THE CANADIAN LAURENTIAN

BY FRANK D. ADAMS AND ALFRED E. BARLOW

[*Abstract*]

Contents

Résumé of former Results

In a former paper,* which appeared in 1893, it was shown that Logan's "Upper Laurentian" does not exist as an independent geological series, the anorthosites, which were considered as constituting its main feature, being in reality great intrusive or batholitic masses, and in a subsequent paper † it was shown that in the remaining portion of the Laurentian two distinct classes of rocks could be distinguished, the first being beyond all doubt igneous rocks, and the second consisting of highly altered rocks of aqueous origin. In addition to these two classes, whose origin could be recognized, there remained a third class whose origin was doubtful.

Recent and present Investigations

Since the appearance of these papers the present writers have been working together in mapping a large area (3,456 square miles) of the Laurentian in central Ontario, in a district especially well suited for purposes of study. Portions of three summers have already been spent in the district, and, as two years more must probably elapse before the work can be completed, it is desired here to present a general outline of the results so far obtained, indicating certain conclusions which seem likely to be reached concerning the origin of the rocks in question.

Present Views concerning Laurentian System

DIVISIONS AND THEIR GENERAL CHARACTERISTICS

The Laurentian system in Canada is now recognized as consisting of two series of rocks, known respectively as the Fundamental gneiss and the Grenville series.

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* F. D. Adams: Ueber das Norian oder Ober Laurentian von Canada. Neues Jahrbuch für Mineralogie, Beil. Bd. viii.

† F. D. Adams: A Further Contribution to our Knowledge of the Laurentian. Am. Jour. Sci., July, 1895.

In petrographical character the Fundamental gneiss is more or less monotonous. It consists chiefly of orthoclase gneisses of various kinds, with which are associated dark basic masses of amphibolite and pyroxene granulite. The orthoclase gneisses have the appearance of igneous masses in which a more or less distinct foliation has been induced by movements. The associated basic masses are very dark or black in color. They are usually indistinctly foliated, but are sometimes quite massive, occurring in bodies of all sizes and shapes scattered through the gneiss, and in the great majority of cases so intimately associated with the latter that it is impossible to separate the two in mapping.

FUNDAMENTAL GNEISS

There can be but very little doubt that this orthoclase gneiss of the Fundamental series is a truly igneous rock. There is no evidence of its having ever formed part of a sedimentary series. The origin of the basic members of the series is as yet uncertain. Similar basic rocks are found the world over in the Archean gneisses, and they are probably closely related in origin to the pyroxene granulites of the Saxon Granulitgebirge. They are probably either differentiation products from the original magma or basic intrusions, whose structural relations and character have been largely masked by the great movements which have taken place in the whole series at a later date.

GRENVILLE SERIES

The Grenville series differs from the Fundamental gneiss in that it contains certain rocks whose composition and minute structure mark them as highly altered sediments. These rocks are in part limestones and in part peculiar gneisses, rich in sillimanite and garnet, having the composition of shales, or very rich in quartz and passing into quartzites, having thus the composition of sandstone. These rocks, as has been shown in one of the papers before referred to, usually occur in close association with one another and are quite different in composition from any igneous rocks hitherto described. These rocks it is which are considered as characterizing the Grenville series. They usually, however, form but a very small proportion of the rocky complex of the areas in which they occur and which, owing to their presence, is referred to the Grenville series. They are associated with and often enclosed by much greater volumes of gneisses and amphibolitic rocks identical in character with those of the Fundamental gneiss. The limestones are also almost invariably penetrated by great masses of coarse pegmatite, and in some cases large occurrences of the limestone are found completely embedded in what would otherwise be supposed to be the Fundamental gneiss. The whole thus presents the character of a series of sedimentary rocks, chiefly limestones, invaded by great masses of the Fundamental gneiss, and in which possibly some varieties of gneisses present may owe their origin to the partial commingling of the sedimentary material with the igneous rocks by actual fusion. There is, however, no reason to believe from the evidence at present available that any considerable part of the series has originated in this last mentioned manner.

RELATIONS OF FUNDAMENTAL GNEISS AND HASTINGS AND GRENVILLE SERIES

The relations of the two series in central Ontario, as determined by the investigations of the last two seasons, throw new light on the problem and indicate its probable explanation. The consideration of those relations will now be taken up in some detail.

The northwestern half of the area in question is underlain by the orthoclase, gneisses, and amphibolitic rocks of the Fundamental gneiss, presenting the characters described above. A smaller area of the same gneiss occurs at the southwestern corner of the map, in the townships of Lutterworth, Snowdon, and Glamorgan, while in the southern and southeastern portions of the area there are other occurrences, which, however, are found to possess a more normal granitic character.

The southeastern portion of the area is underlain by rocks of the so-called Hastings series, a series consisting chiefly of thinly bedded limestones, dolomites, etcetera, cut through by great intrusions of gabbro-diorite and granite. These limestones and dolomites are usually fine grained and bluish or grayish in color, with thin interstratified layers holding sheafy bundles of hornblende crystals and, as compared with the limestones of the Grenville series, are comparatively unaltered. They form beyond all doubt a true sedimentary series, and in the southeastern corner of the area are associated with conglomerates or breccias of undoubtedly clastic origin.

Between the great area of Fundamental gneiss in the northwest and the Hastings series in the southeast of the sheet there lies an irregular shaped belt of rocks, presenting the characters of the typical Grenville series as above described, the limestones being in all cases coarsely crystalline white marbles, although often more or less impure. The strike of the foliation of the Grenville series follows in a general way the boundaries of the Fundamental gneiss.

The relations of the Grenville series to the Fundamental gneiss are such as to suggest that in the former we have a sedimentary series which has sagged slowly down into and been invaded by intrusions of the igneous rocks of the latter series when those were in a semi-molten or plastic condition. The contact of the Fundamental gneiss and the Grenville series would appear, therefore, to be in most cases at least a contact of intrusion.

The question of the relation of the Grenville series to the Hastings series in the southeastern part of the area then presents itself. Although repeated traverses have been made from one series into the other, no sharp line of division has as yet been found. Toward the southeast the limestones of the Grenville series in many places, while still highly crystalline, seem to be less highly altered, and finally, as the Hastings series is approached, they present in places the bluish color of the limestones of the latter series, so that it is often impossible to determine to which series they should be referred. The limestones of both series also have the very numerous, little, interstratified, impure or gneissic bands so frequently referred to in descriptions of the limestones of the Grenville series, making the resemblance still more complete. In fact, although the true relations of the two series are obscured by the presence of numerous great intrusions of granitic and basic pyroxenic rocks, and can only be determined with absolute certainty by the completion of the mapping, the investigations so far indicate that in the region in question the Hastings series is the source from which the limestones and sedimentary gneissic rocks of the Grenville series have been derived. The Hastings series would seem to represent the series in its original form, which when invaded, disintegrated, fretted away, and intensely metamorphosed by and mixed up with the gneissic magma of the Fundamental gneiss, into which it had sagged down, gives rise to the Grenville series described above.

Age of the Hastings Series

Concerning the age of the Hastings series, but little is known as yet. In the extreme southeast corner of the area, however, as above mentioned, its clastic character is well marked, breccias and conglomerates, often greatly deformed by pressure, being present, as well as certain fine grained and comparatively unaltered limestones, in which a very careful search may be rewarded by the discovery of fossils. Like the Grenville series to the east and west, it is unconformably overlain by and disappears beneath the flat lying Cambro-Silurian rocks of the plains, which limit the protaxis on the south, and is separated from these latter by an immense erosion interval.

Tentative Conclusions

Further investigations in the area as well as in that adjoining it on the east, which is now being mapped by Dr R. W. Ells, will, however, it is hoped, before long throw additional light on the age of this very interesting and important series of rocks. If further investigation proves that the relations of the several series have been correctly diagnosed and that the explanation of these relations given above is correct, the Laurentian system of Logan will resolve itself into an enormous area of Fundamental gneiss, which is essentially of igneous origin, and which there is every reason to believe forms part of the original crust of our planet, perhaps many times remelted and certainly in many places penetrated by later enormous intrusions of igneous rocks, into which Fundamental gneiss when in a softened condition there have sagged down in certain places portions of an overlying series consisting chiefly of limestones of unknown age.

In connection with the foregoing, there was read the following:

NOTE ON "ORIGIN AND RELATIONS OF THE GRENVILLE-HASTINGS SERIES OF THE CANADIAN LAURENTIAN"

BY R. W. ELLS

In connection with the statements advanced in the preceding paper by Messrs Adams and Barlow, it is but right that the conclusions reached from the study of the similar rocks in their eastern and northern extension should be stated.

The investigations in this quarter have now been carried on for six years, and have covered a very large area to the north of the Ottawa, in which is included the typical Grenville series of Sir W. E. L. Logan, and extended far up the Gatineau river, while to the westward the work has been carried on till the vicinity of the area described in the accompanying paper has been reached. It may be said, therefore, that the detailed examination of the rocks which make up the Grenville and Hastings series has extended over an area about 250 miles in length by 75 miles in breadth.

The more recent and probably sedimentary origin of the limestones and associated gneisses of the Grenville series as distinct from the great mass of the underlying Laurentian Fundamental gneiss was pointed out some years ago in a paper by the author read before this Society. The subsequent investigations on these rocks to the west and southwest showed that the conclusions then presented were correct, but that as the work extended westward to the south side of the Ottawa the character of the various groups of rocks gradually changed. The areas of limestone became much more extensive, and there was a large development of hornblende and other dark colored rocks rarely seen to the north of the Ottawa. The limestones, also, were very often highly dolomitic, and in certain areas were blue and slaty, with but little of the aspect of the Grenville limestones, except where they were in close contact with masses of intrusive granite or diorite. There is also in the rocks of this group to the south of the Ottawa, where they have been styled the Hastings series from the fact that they were first studied in the county of Hastings, a very considerable proportion of schists—micaceous, chloritic, and hornblendic—with certain regularly slaty beds and others of true conglomerate containing quartz pebbles. In certain portions the lithological resemblances between the Grenville and Hastings rocks are very close, and they may for all practical purposes be regarded as one and the same series. From a number of sections made in the counties of Renfrew on the south of the Ottawa and in Pontiac to the north of that river, it would appear that the original Grenville limestones and associated gray and rusty gneisses form the lower part of the series, since it is only on the development eastward toward the typical Hastings locality that the characteristic Hastings schists and associated strata are met with.

The paper was discussed by B. K. Emerson, J. P. Iddings, Charles H. Smyth, Jr., J. E. Wolff, and H. W. Turner. It is published in full in the American Journal of Science, volume III, March, 1897, pages 173–180.

The second paper was the following:

WEATHERING OF MICACEOUS GNEISS IN ALBEMARLE COUNTY, VIRGINIA

BY GEORGE P. MERRILL

The paper was discussed by A. C. Lane, Louis V. Pirsson, J. F. Kemp, and the author. It is printed as pages 157–168 of this volume.

The paper next read was entitled—

THE CRYSTALLINE AND METAMORPHIC ROCKS OF NORTHWEST GEORGIA

BY C. WILLARD HAYES AND ALFRED H. BROOKS

The paper was discussed by A. C. Lane, Arthur Keith, and A. H. Brooks. A brief abstract is published in Science, volume 5, January 15, 1897, page 97.

The following paper was then read :

GRAIN OF ROCKS

BY ALFRED C. LANE

[*Abstract**]

Contents

Introduction

The slower crystals form, the more likely they are to be coarse. If we wish to produce a glassy candy, like barley candy, the syrup should be cooled as quickly as possible. Among rocks we have the glassy lava of obsidian and the coarsely crystalline granite of the same composition. In the case of obsidian, the difference is generally associated with more rapid consolidation. More precisely, we may say that whether a solid be formed from liquid, as beds of salt are thrown down from the sea, or formed by loss of heat, as in the chilling of lava, or from the escape of gas, as when $C\,S_2$ escapes from tire cement, the more rapid the solidification when crystallization results, the smaller are the constituent crystalline grains.

Grain as affected by Rate of Cooling

Singling out one particular manner of solidification for attention, namely, that of solidification by cooling, let us at first confine our attention to the case of a sheet so extensive with regard to its thickness that we need only regard its cooling in the direction of its thickness. Suppose it to have a uniform initial temperature and constant conductivity and its surfaces kept at a constantly fixed lower temperature while it cools, such will roughly be the conditions of a dike suddenly intruded into wet rocks.

As it cools, the temperature close to the surfaces will fall very suddenly nearly to that of the fixed temperature of the margin. Toward the center the cooling will be less rapid. In fact, there will be a short space of time, increasing toward the center, during which the cooling effect of the lower temperature at the margins will be hardly felt. Then the cooling will increase and as the temperature drops to near that of the margin grow less rapid once more.

These facts are illustrated by figure 1, which is a sketch from a plate showing the cooling of an igneous sheet 100 feet thick and of an indefinite extent. The value 400, as given in Thomson and Tait's Natural Philosophy (page 476), is used for the conductivity, and temperature curves are given not only for the center, but for points at various distances from the center toward the margin as indicated. These

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*The mathematical treatment of the subject and a plate illustrating the solution, the application to Keweenawan ophites, and the chemical relations are reserved for fuller treatment in volume vi of the Michigan Geological Survey reports. The experimental illustrations will not be found there.

curves show by ordinates parallel to *O B* the temperature corresponding to the times after the beginning of cooling represented by their abscissæ parallel to *O T*. As above described, the sheet is assumed to cool from a uniform initial temperature, *u*, toward the constant unvarying temperature of the margin (*O*). The same plate is applicable to other conductivities, sizes of sheet, and initial temperatures, by changing the scales appropriately.

So long as the center has not cooled perceptibly, which, in the case of figure 1, is .2 of a year, the time required for any point to cool down to a certain amount, or by a certain amount, may be shown to vary as the square of the distance of the point from the margin, independently of the size of the flow. Experiments later mentioned show that when consolidation takes place in this period the grain of the constituent granules of the substances used is such that—*the linear dimensions are as the distance from the margin*; hence, *the grain, measured by areas of cross-sections of constituent granules,* is as the slowness of cooling.*

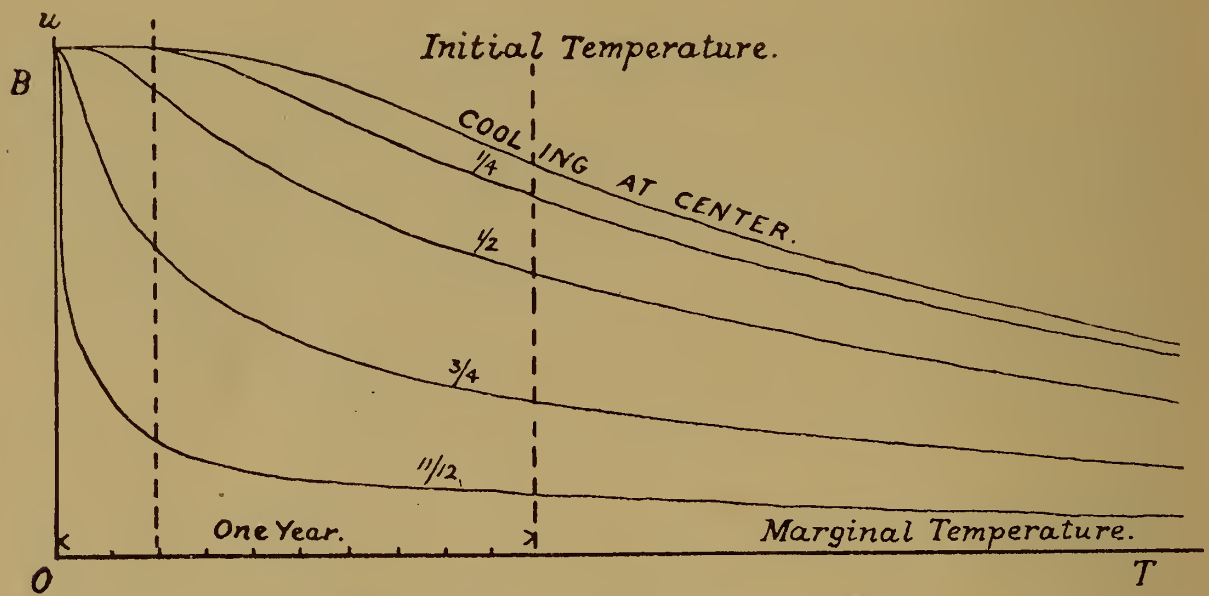

FIGURE 1.—*Curves of Cooling in igneous Schist*

After the cooling has so far proceeded that the center has cooled about one-fourth of the interval between the initial temperature and the margin—that is, in the case of figure 1, a year—the rate of cooling when a point reaches a particular temperature is practically the same, regardless of the position of the point. This is when all terms but the first of the sesries in the mathematical equation given at the end may be neglected.

So far as the solidification falls in this period the grain will be uniform and not vary with the distance from the margin.

If the formation of a mineral is controlled wholly by the rate of cooling and no latent heat evolved by chemical reactions or other disturbing factor need be considered, then according as its range of formation is near to the marginal temperature or to the initial temperature will we have a more or less broad central zone of uniform grain. The hotter the temperature at which the margin is kept, or the hotter the initial temperature of the sheet, or the lower the temperature of consolidation, the broader the central zone of uniform grain.

*In measuring the grain in rock-sections, as such a section may merely cut a small marginal section from a grain, I took the largest section in each of several areas of observation.—A. C. L.

If we remove the condition that the surfaces of a sheet be kept at a fixed temperature and assume the appreciable alteration of temperature due to the intrusion of the hot sheet *B C*, figure 2, to be confined to a zone *A D*, the center of which is also the center of the cooling sheet *B C*—suppose the conductivity uniform and constant throughout—then the temperature of any point *P* of this zone, within or without *B C*, is very easily derived from those of two points in a hypothetical hot sheet of width equal to that of *A D*, whose initial temperature, conductivity, etcetera, are those of the intruded hot sheet *B C*, the temperatures of the margin of the hypothetical sheet *E F* being kept the same as that which *A B* and *C D* initially

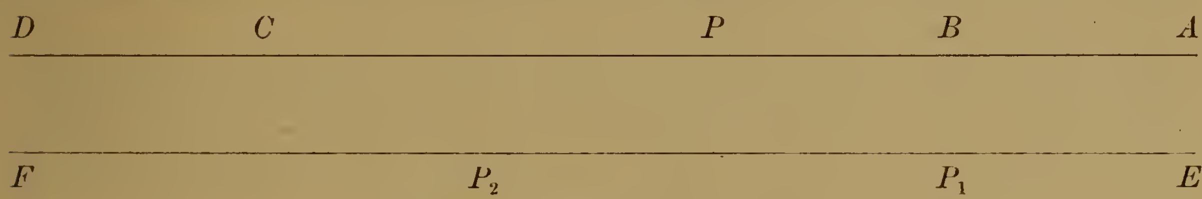

FIGURE 2.—*Temperature Diagram.*

Illustrating relation between sheets, which have margins kept at a fixed temperature and those which have not.

had. For the temperature of *P*, any point between *B* and *C* is an average of that of the temperatures of two points, P_1 and P_2, as far distant from the surfaces *E* and *F* as is *P* from *B* and *C* respectively—that is, *P B* is P_1 *E; P C* is P_2 *F;* but if *P* lie outside *B C*, then the difference of the temperatures of P_1 and P_2 at the same time must be taken. Thus the solution of this case may be made to depend upon the other. The temperature at *B* will be half way between the temperatures of *A B* and *B C*, to start with, and will fall more slowly from that temperature than will the center when it has cooled down to that temperature. Hence, *if the temperature of solidification of a given mineral is about half way between that of the molten dike and its contact zone, the grain might be coarser at the margin than at the center.* This is suggested as a possible explanation for the so-called marginal porphyritic facies of granites in some, not all, cases. In the case of a contact zone, therefore, there may be no marginal zone of finer grain.

VERIFICATIONS

In experimental verification I have made use of the principle that if *A B C D*, figure 3, represent the cross-section of a cooling mass, *A B*, *B C*, and *C D* being

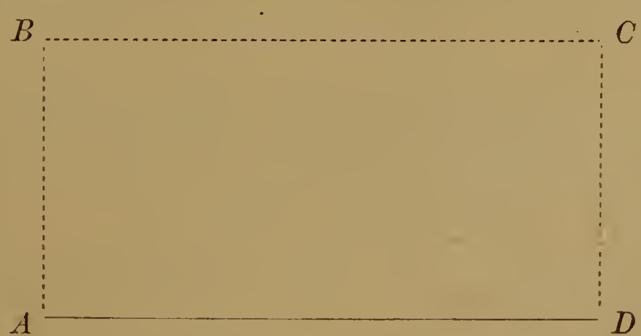

FIGURE 3.—*Temperature Diagram.*

Illustrating cooling from one surface only.

covered by nonconductors and cooling allowed only through *A D*, the heat flow and attendant phenomena will practically be the same as in a sheet of twice the thickness *A B*. Hence I have used a baking-powder can set on ice and swathed in flannel. The curves of cooling agreed with theory.

Sulphur melts at 115 degrees Centigrade and solidifies at 111½ degrees Centigrade. If melted near 115 degrees and poured off to cool, we find (1) that the grain is coarser from margin (*A D*) to the center (*C B*) ; (2) that the grain is equally coarse at the same distance from the bottom in pourings, differing in thickness, but otherwise alike, and (3) that a linear magnifying power of 2 will make the grain apparently twice as coarse as at twice the distance from the margin.

The melilite slags, already described,* show similar laws.

The augite of the Keweenaw luster, mottled melaphyres—that is, ophites—follows the same laws. It increases in size to the center, the size being nearly independent of the size of the flow. In the great flow known as the Greenstone the average diameter of the augite patches at 400 feet from the margin is about one inch and in direct proportion for greater and less distances.

We find, however, this law modified by chemical considerations, so that where the augite is more abundant it is coarser, and where less abundant finer. Some of the Keweenawan flows show considerable variation of this sort, the augite being more abundant in the bottom part of the flow. Large dikes in the Huronian, probably of the same period of eruptive activity, show a central zone, where the augite has a uniform grain.

Sugar and water illustrate aqueo-igneous fusion. Sugar fuses at 164 degrees Centigrade, and a solution of sugar and water can be raised to that temperature with continual loss of water without crystallization. Solidification as a clear glass takes place at a comparatively low temperature—about 60 degrees Centigrade. Hence there is always a central zone of uniform grain. The more water there is, the more is the tendency to be crystalline rather than glassy, and aqueous glasses readily devitrify. Spherulites may be obtained, and by stirring during cooling, or partial cooling during heating, porphyritic texture. The analogy in behavior to SiO_2 and silicious glasses is very strong.

Mathematical Equations

Let u be the temperature at a time t after the beginning of the cooling of a point at a distance of x from the margin of the zone of affected temperatures. Let u_0 be the initial temperature. Let e be the exponential base, π the ratio of circumference to diameter in the circle and a a constant depending on the conductivity. Let

$$q = e^{-(\pi a/c)^2 t}$$

Suppose the whole zone whose temperature is affected to have breadth c, and a sheet of breadth $2w$ to be inserted at a point at a distance from the same margin from which x is measured such that its center is at m.

Then by Riemann,†

$$\pi/4 \;.\; u/u_0 = \sum_{n=1}^{n=\infty} \sin(n\pi m/c) \;.\; \sin(n\pi w/c) \;.\; \sin(n\pi x/c) \;.\; q^{n^2}/n.$$

* Bull. Geol. Soc. Am., vol. 6, p. 469.

† Differential-gleichungen, 1882, § 57.

When the cooling is symmetrical, m is $c/2$, and when the sides of the sheet are kept at a fixed temperature, w is also $c/2$. These are the cases above considered and illustrated by figure 1.

The problem is akin to that of the cooling of the earth and may be made to depend upon the solution of that. For distinction sake we let the temperature of a point in a sheet cooling under the conditions given above as applicable to figure (1) be Vm, the point being at a distance x from the margin such that x/c is m, where c is the thickness of the sheet, and if we let the temperature of a cooling globe of radius c cooling under similar conditions,* at a distance from the center of r such that r/c is m, be u_m, it may be shown that $V_m = m\,u_m + (1 - m)\,u_{1-m}$.

Discussion of this paper was omitted in order to allow time for the exhibition of some material from the trap sheets of the Connecticut valley by the chairman, B. K. Emerson.

The Petrographic Section then adjourned.

After the retiring of the Petrographic Section (referred to on page 393), Vice-President Orton resigned the chair to President Le Conte and the proceedings in general session were continued.

The first paper was read as follows:

MECHANICS OF GLACIERS, MORAINES, AND STRATIFICATION

BY HARRY FIELDING REID

Remarks were made by the President. A brief abstract is published in Science, volume 5, January 15, 1897, page 91.

The next paper was by the same author:

VARIATIONS OF GLACIERS

BY HARRY FIELDING REID

An abstract is published in Science, volume 5, January 15, 1897, page 91.

*As investigated by Woodward in Annals of Mathematics, vol. iii, 1887, p. 77, equation 10.

The following paper was illustrated by lantern views:

PHYSIOGRAPHY OF THE EASTERN ADIRONDACKS IN THE CAMBRIAN AND ORDOVICIAN PERIODS

BY J. F. KEMP

Contents

Introduction

The waters of lake Champlain lie in a depression, whose eastern boundary, except for a short distance at its southern extremity, is made up of Paleozoic strata. The larger part of the western shore is also composed of the same formations, but in many places the pre-Cambrian crystallines jut out in ranges of hills to the water's edge, and at all points south of Port Kent they are not far back from the lake.

The relations of the Paleozoic strata to the crystallines furnish some interesting data regarding the physiography of what may be most fittingly called the "Adirondack island" of early Paleozoic time.

Geology of the Champlain Region

The researches of several observers, of whom the latest and most important is C. D. Walcott, have shown the presence of the Lower, Middle, and Upper Cambrian strata in Vermont. The Lower and Middle Cambrian do not cross the lake, for the Upper Cambrian or Potsdam, in the form of conglomerates and sandstones, the latter vastly predominating, is the oldest Paleozoic and unmetamorphosed formation present on the New York shore. Prolonged and careful search has been made by several observers, including the writer, in order to test this statement, but thus far no facts have been found to modify it. Conformably on the Potsdam the Calciferous, Chazy, Trenton, and Utica formations follow, but none later than the Utica have been recorded except the Glacial and post-Glacial drift, sands, and clays.

Interpretation of the Geology and Statement of the Problem

It is evident from the above that the Lower and Middle Cambrian strata were laid down well to the east of the present limits of the crystallines, and that with their gradual subsidence the Cambrian sea crept westward, so that the Potsdam

Altitudes of 1,000 feet and over are horizontally lined. Paleozoic outliers, shaded black, are all Potsdam except the one on Schroon lake, which is Calciferous. Along lake Champlain the Ordovician strata are indicated by vertical lines. Except for glacial drift, all the rest of this area west of lake Champlain shows crystalline rock so far as known.

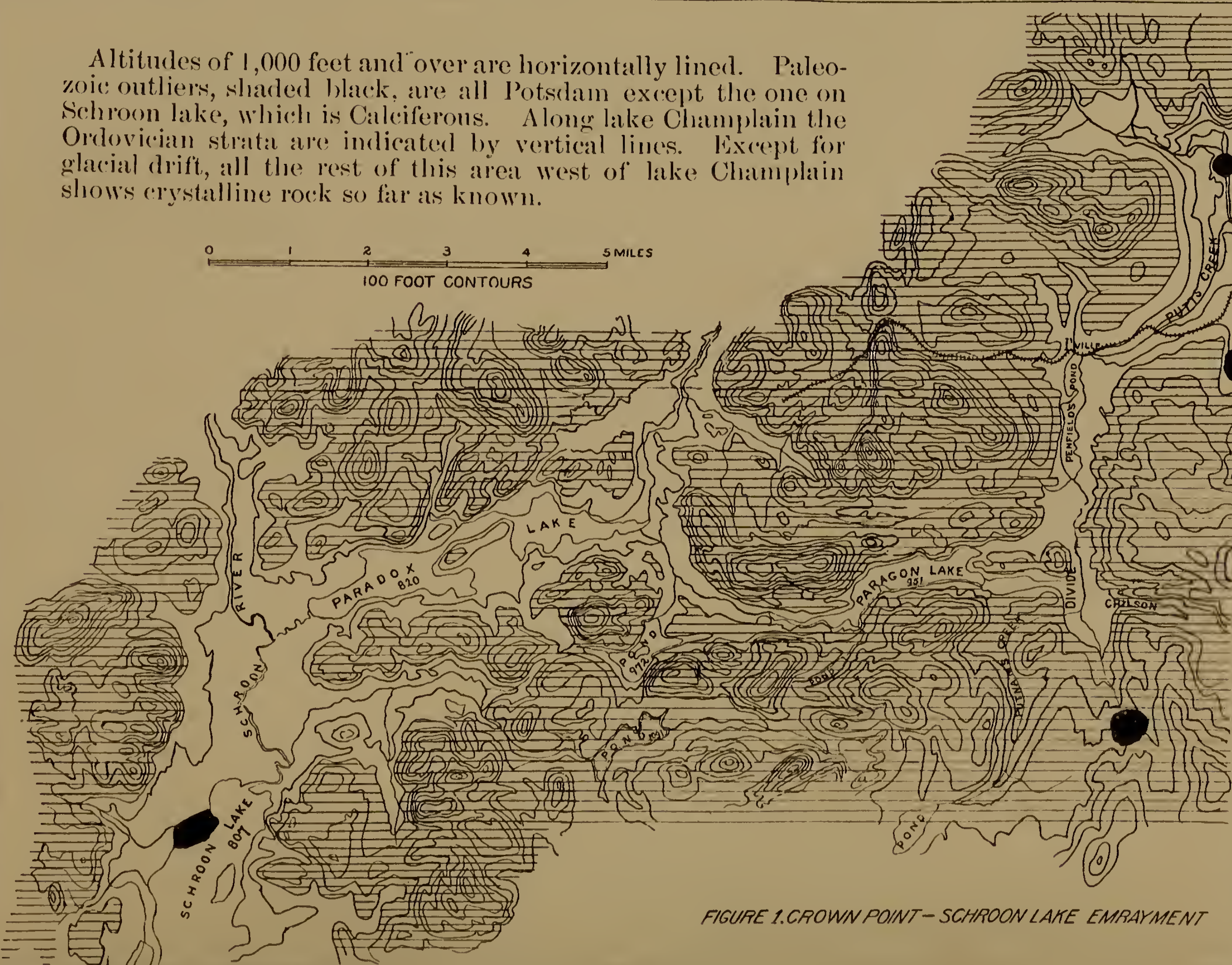

FIGURE 1. CROWN POINT–SCHROON LAKE EMBAYMENT

FIGURE 2. TICONDEROGA EMBAYMENT

CROWN POINT-SCHROON LAKE AND TICONDEROGA EMBAYMENTS

sandstones were deposited along an encroaching shoreline.* The commonest Paleozoic outlier now remaining in the interior of the mountains belongs to the Potsdam, but Calciferous limestone is met in the most remote one of all here specially described, so that it is probable that at least the Trenton limestone and the Utica slate were also deposited in the valleys later described. It should be appreciated, however, that on the southwest side of the Adirondack crystalline rocks the Trenton limestone extends farthest into them, having apparently buried the earlier strata. This may indicate a different amount of submergence between the two sides of Adirondack island.†

Previous Work bearing on the Problem

Hitherto attention has been chiefly directed to the progress of events on the sea-bottom, but in pursuing the question further it is also interesting to inquire what were the conditions prevailing over the land area during these times. The crystalline rocks had all been formed and metamorphosed before the Cambrian opened. The igneous rocks had largely been squeezed into gneisses; the limestones had become coarse, graphitic marbles; and very quartzose, but not abundant, sillimanite gneisses indicate sandstones. The nature of the other acidic gneisses is yet in doubt. Unmetamorphosed pre-Potsdam diabase dikes have been shown by H. P. Cushing ‡ which represent this pre-Cambrian or early Cambrian interval. During the early Cambrian the Adirondack height-of-land must have been subjected to the ordinary processes of erosion and land sculpture, and it is the purpose of this present paper to show the traces of their work that are still discernible. The old topography has been greatly masked by later faults, in which the Paleozoics have shared, but enough in the way of remnants and outliers of unaltered and almost horizontal Cambrian and Ordovician sediments remain to be of real significance.

Influence of Limestones on Topography

In directing the early as well as the present lines of drainage, which latter probably in large part adhere to the early ones, the coarse, crystalline limestones had a very large influence. They may not be thick, continuous, or extensive as regards individual beds, but in the aggregate they were very serious factors, for they are to be detected in almost all the large depressions.

Keeseville Embayment

Just south of Port Kent a range of crystalline rocks juts out into the lake as the bold headland of Trembleau point. Around its northern portion the Potsdam sandstone forms an embayment that reaches to Keeseville and that furnishes the walls of the interesting gorge of the Au Sable chasm, familiar to so many visitors to the region. From Keeseville the line of the Potsdam bears away to the north-

* See in this connection C. D. Walcott, Bulletin 30, U. S. Geological Survey, 1886, p. 24 and fig. 2. Mr. Walcott even suggests the former presence of (Upper) Silurian strata over the Adirondack crystallines, but beyond this reference to them he does not discuss their physiography.

† See the recently issued geological maps of New York state, the large one by James Hall and W J McGee in 1894, and the small one, which is as regards the eastern Adirondacks more accurate, by F. J. H. Merrill, in Bulletin New York State Musuem, vol. iii, number 15, 1895.

‡ H. P. Cushing: On the Existence of Pre-Cambrian and Post-Ordovician Trap Dikes in the Adirondacks. Trans. N. Y. Acad. Sci., vol. xv, 1896, p. 248.

west, and in at least one place it entirely encircles an outlying hill of gabbro.* In this region the contacts have been studied by H. P. Cushing, whose inferences are in general very much like those of the writer.

Willsboro-Essex Embayment

Southward along lake Champlain, in the townships of Willsboro and Essex, the Potsdam and Ordovician sediments make a pronounced embayment in the bight north of Split Rock mountain. The Potsdam sandstone extends farthest inland and is present on both sides of the Bouquet river as far south as Whallonsburgh. It reaches 300 feet above tide (200 feet above Lake Champlain) and lies very flat, the dip being but 10 degrees. By comparison of the geological maps of Willsboro and Essex † with the Willsboro atlas sheet of the U. S. Geological Survey, the relations appear very distinctly.

Westport Embayment

Still farther south beyond the ridge of the Split Rock range, the Paleozoics set up in a deep bay at Westport ‡ and reach the 300-foot contour. They extend seven miles southward, and at the latter extreme reach the 400-foot contour. Some three miles of gabbro and crystalline limestone then form the shore until at Port Henry the Potsdam is again met. The maximum width of the Paleozoics in the Westport embayment is about two miles. They embrace strata from the Potsdam to the Trenton.

Port Henry Embayment

At Port Henry another embayment of Potsdam with a little faulted Calciferous comes in and runs up to the southwest to an altitude of over 600 feet above tide. It lies on the north side of Bulwagga mountain, but has a quite flat dip.

Résumé

In all the cases hitherto cited faulting no doubt plays a considerable part, and the ever-present glacial drift quite generally masks the actual contacts, but none the less there is no doubt that early Cambrian or pre-Cambrian depressions determined in large part the locations of the areas of deposition. The following cases are, however, more significant.

Crown Point-Schroon Lake Embayment

On the south side of the embayment at Port Henry, Bulwagga mountain, as stated, closes in and forms at the same time the northern boundary of the valley in which is the village and most of the township of Crown Point.§ The accompanying map, plate 51, figure 1, has been prepared by tracing off the 100-foot con-

* See the geological maps of New York, to which reference has just been made.

† T. G. White: The Geology of Willsboro and Essex Townships, Essex County, N. Y.; Transactions N. Y. Acad. Sci., vol. xiii, p. 214, plate vi. J. F. Kemp: Preliminary Report on the Geology of Essex County, N. Y.; Rept. of N. Y. State Geologist for 1893, pp. 460-462.

‡ See map of Moriah and Westport townships, by J. F. Kemp, in the Bulletin of the New York State Museum, vol. iii, number 14, plate i.

§ For a small geological map of Crown Point township, see writer's Report on the Geology of Essex County, just referred to, p. 456.

tours of the Ticonderoga, Paradox Lake, and Schroon sheets of the United States Geological Survey for this particular area, and then reducing to about one-third the original. From the lake Champlain shore at Crown Point village the Potsdam sandstone sets back up the valley of Putts creek. One outlier is met at Crown Point Center, about three miles inland; another is a mile farther on the main stream; a third lies on a small tributary to the northwest and on the 700-foot contour, while a fourth is at the head of a southerly tributary in a little cul-de-sac on the 800 to 900-foot contours; a fifth little area is on the flanks of Bulwagga mountain nearer the lake on the north side of the valley, and Calciferous cherty limestone is abundant on the shore.

Returning now to the valley of Putts creek and following it upstream, it will be seen that it flows from Penfields pond at the little hamlet of Ironville (called I'ville on the map), and that the pond continues the valley southward, but that the 1,000-foot contour is not far back from its shore. Putnams creek is the inlet, and in a swampy area has an almost imperceptible divide from the head feeder of Paragon lake (formerly known as Long pond). Following up a little feeder of the creek and nearly due south a small outlier of Potsdam is met, over 1,200 feet above tide and away up in a little, narrow valley. Its strike is north-northeast and its dip 13 degrees west. The relations of the drainage at the head of Paragon lake are curious and interesting. It would require but a very little to change the lake's discharge to the Putnam Creek outlet.

Following along the valley of Paragon lake, at the 951-foot level, and that of Paradox lake, at 820, with notably sluggish streams all through this region, we pass into the broad valley of Schroon lake, whose upper end has been manifestly filled in in very recent time. At Schroon Lake post-office, on the west shore and less than a mile from the inlet, is an area of Calciferous, blue, flinty limestone striking north 60 degrees east and dipping 25 degrees west. It is exposed for a quarter of a mile along the shore and has a total visible thickness of 75 feet.* This little outlier is of extreme interest, occurring as it does fully 20 miles from lake Champlain and 40 miles from the nearest Paleozoic outcrop down the valley of Schroon lake, Schroon river, and the Hudson.

It is the writer's belief that all of this depressed area which has been sketched out above was once filled with the Paleozoic sediments, and that the erosion since these early times has been largely engaged in cleaning them out. There has been considerable faulting, no doubt, and elevation of the Potsdam above Chilson, but still the present streams all appear to be near local baselevels. The Schroon, for example, must be followed up to the limits of the map before the 900-foot contour is cut, and then 6 miles farther yet before the 1,000 one is met. This is a very low gradient for an Adirondack creek. Probably the ice of the Glacial period scoured out no small amount of Paleozoic remnants.

Ticonderoga Embayment

Figure 2 of plate 51 is a sketch map of the relations at the outlet of lake George at Ticonderoga. On the lake Champlain shore the Ordovician strata are strongly

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* This area was first reported by Charles E. Hall, who speaks of it as Chazy, and states that fossils occur in it. The writer was unable to find fossils, and regarded it as Calciferous on lithological grounds. See C. E. Hall: Thirty-second Ann. Rep. N. Y. State Museum Nat. History, 1879, p. 139. Fossils would of course settle the question.

developed and have been mapped by Brainerd and Seely.* They follow up the Ticonderoga (locally called "Ti") river about half way to lake George, in whose valley they do not appear again for some miles, or until the town of Bolton, on the west shore, is reached, far beyond the limits of this little sketch map. The sediments do appear, however, in the valley of Trout creek, to the west of the outlet, in two small outliers. The dip is only 5 to 10 degrees, and the disturbance is therefore slight. Presumably an old Cambrian channel was present in this depression.

Other Outliers

Mention has just been made of the exposures at Bolton, on lake George. Potsdam and Ordovician are both present, as shown by the recent large geological map of the state. At the south end of lake George, tongues of Ordovician strata stretch in from the parent areas on the south. Attention should also be called to the remarkable outlier of Paleozoics, showing Potsdam, Calciferous, Trenton, and Utica beds at Wells or Wellstown, on the Sacondaga river. It was first discovered and described by Vanuxem in 1842, and has lately been figured with many details by N. H. Darton.†

Conclusion

The facts above set forth lead to the conclusion that the present large depressions and lines of drainage were to a great degree outlined in Cambrian time. They have been more or less modified by later faulting, but the vast erosion that has taken place since the Cambrian, removing we know not how much of post-Ordovician strata as well from the Adirondack region, has not sufficed to entirely clear the valleys of the Cambrian and Ordovician sediments. Much of the later excavation and removal of the sediments, especially of the Potsdam, was probably done by the great ice-sheet, for Potsdam boulders are extraordinarily abundant and widespread in the drift, even far into the mountains. Its abundance makes the observer question if it has all been derived from the large exposures north and east of the mountains. Glacial striæ, so far as noted, are about north 50° to 60° east.

Alternative Hypothesis

If the above explanation of the Paleozoic outliers be not accepted, it is necessary to assume that the Adirondack region was a peneplain in later Cambrian time, and that the Cambrian-Ordovician sea spread over it, depositing a mantle of sediments, all of which have been removed except these small remnants, which have been dropped by great faults and so preserved in the fault valleys. Although faults, as has been often stated, are recognized by the writer as strong factors in the topography, the first conclusion seems to him much the more probable and reasonable.

Remarks were made upon the matter of the paper by M. R. Campbell, H. P. Cushing, R. S. Tarr, F. D. Adams, A. C. Lane, and H. F. Reid.

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* Bull. Am. Mus. Nat. History, June 1890, vol. iii, p. 10. See also the writer's Report on Essex County, already cited, p. 452.

† Geology of the Mohawk Valley, Rept. of N. Y. State Geologist for 1893, p. 415 and p. 429. Mr Darton also cites an outlier of Trenton limestone five miles south of Kattskill bay, on the east side of lake George, p. 428. It lies against a fault.

At this point several titles of papers on the printed program were passed on account of the absence of authors, and the next paper presented was as follows:

ON THE SOUTHERN DEVONIAN FORMATIONS

BY H. S. WILLIAMS

An abstract is published in Science, volume 5, January 15, 1897, pages 92, 93.

The last paper of the morning session was the following:

AGE OF THE LOWER COALS OF HENRY COUNTY, MISSOURI

BY DAVID WHITE

The paper is printed as pages 287–304 of this volume.

Following the reading of this paper, a recess for lunch was taken.

The Society reconvened at 2 p. m., and the matter laid upon the table at the morning session was taken up. The following letter was read by the Secretary:

LETTER OF LIEUTENANT R. E PEARY AND RESOLUTIONS RELATING THERETO

41 Remsen Street, Brooklyn, *December 28, 1896.*

To the President of the Geological Society of America.

Dear Sir: It is my intention to send a ship north again next summer to bring home the big meteorite which owing to the drifting ice I was unable to embark last summer.

My ship will be a thoroughly suitable one, with a competent ice master, and there will be accommodations on board for a party of scientists who may wish to make investigations in high northern latitudes.

The glacial and geological work of Heilprin, Chamberlin, Salisbury, Tarr, and Barton in connection with my expeditions of the past five years have been of such value and interest that I have thought you might consider the above opportunity worthy of being brought to the attention of your Society. Last summer on board the "Hope" with Professors Tarr and Barton the possibility was suggested of several parties, each under the auspices of some university or institution, and each entirely independent as to method of work and proprietorship of results, yet all working on certain general lines formulated perhaps by a committee appointed by your Society, so that the work of all could be combined and its value thus largely enhanced.

Each party taking a certain section of Arctic coast, it would be possible to cover a wide range in latitude with synchronous studies and observations, which I am sure would be of great value.

Parties should be of from three to six individuals; the duration of the voyage would be about three months (not more), and the voyage would be entirely free from danger.

Any of the gentlemen mentioned above in the third paragraph who may be present at the meeting will, I feel confident, give you or the Society any further detailed information that may be desired in regard to summer work in the Arctic regions.

Trusting that you will pardon the liberty I have taken in trespassing upon your attention, I am,

Very respectfully, R. E. PEARY, *U. S. N.*

The following resolutions were offered by George H. Barton, and were adopted:

"*Resolved*, That the Geological Society of America endorse Lieutenant Peary's suggestion that the coast of Greenland presents an exceptionally fine field for the investigation of glacial phenomena, as well as in a more limited degree of the other natural sciences, and recommends that the universities, colleges, and various scientific organizations of the country consider the matter of cooperation with Lieutenant Peary, in the summer of 1897, by sending independent parties to be placed at various localities along the Greenland coast to carry on synchronous work during a period of five to six weeks.

"*Resolved*, That the thanks of the Geological Society of America be rendered to Lieutenant Peary for having brought the matter of this form of Arctic work to the attention of the Fellows of the Society."

Professor W. B. Clark made explanation of several large colored wall charts showing the areal geology of the continents of Asia, Africa, South America, and Australia which he had placed upon the walls of the room.

The following resolution of thanks was presented by W. B. Clark, and unanimously adopted:

"*Resolved*, That the success of this meeting and the enjoyment of the members have been in great measure due to the admirable arrangements which have been perfected for the entertainment of the Society. It is therefore appropriate that recognition should be given to those who have so largely aided in bringing about these results.

"Thanks are due to the Secretary of the Smithsonian Institution and the Acting Director of the United States National Museum for the use of this room for the daily sessions of the Society, to the president and officers of the Columbian University for the use of its lecture hall for the annual address of the President of the Society, to the board of managers of the Cosmos Club for the privileges of its clubhouse, and to the local committee of the Society for the perfection of the arrangements which we have enjoyed.

"It is therefore the sense of those present that the hearty thanks of the Society be extended to all who have thus united in rendering this meeting both successful and enjoyable."

The following paper was presented briefly in abstract:

A COMPLETE OIL WELL RECORD IN THE McDONALD FIELD BETWEEN THE PITTSBURG COAL AND THE FIFTH OIL SAND

BY I. C. WHITE

A brief abstract is published in the Journal of Geology, volume 5, January–February, 1897, page 103.

The next paper was entitled—

STRUCTURE OF THE NEWARK FORMATION OF WESTERN NEW JERSEY

BY HENRY B. KÜMMELL

Remarks were made by A. C. Lane, G. K. Gilbert, Arthur Keith, and W. H. Mathews. A brief abstract is published in Science, volume 5, January 15, 1897, page 93.

The following paper was then read:

UPPER CRETACEOUS FORMATIONS OF NEW JERSEY, DELAWARE, AND MARYLAND

BY WILLIAM B. CLARK

Remarks were made by Angelo Heilprin. The paper is printed in full as pages 315–358 of this volume.

The next paper was read by Mr. Stanton, entitled—

STRATIGRAPHY AND PALEONTOLOGY OF THE LARAMIE AND RELATED FORMATIONS IN WYOMING

BY T. W. STANTON AND F. H. KNOWLTON

The paper is printed as pages 127–156 of this volume.

The following paper was then read:

PRINCIPAL FEATURES IN THE GEOLOGY OF SOUTHEASTERN WASHINGTON

BY ISRAEL C. RUSSELL

Remarks were made by J. S. Diller. An abstract of the paper is printed in the American Journal of Science, volume 3, March, 1897, pages 246–248.

The next paper was illustrated by a set of specimens and lantern views.

NATURE, STRUCTURE, AND PHYLOGENY OF DAEMONELIX

BY E. H. BARBOUR

The paper is printed as pages 305–314 of this volume.

The last paper on the printed program was read by title:

GYPSUM DEPOSITS OF KANSAS

BY G. PERRY GRIMSLEY

The paper is printed as pages 227–240 of this volume.

The following seven papers, which had been carried to the end of the program under the rule concerning the order of reading, were read by title:

EVIDENCES OF NORTHEASTERLY DIFFERENTIAL RISING OF THE LAND ALONG BELL RIVER

BY ROBERT BELL

The paper is printed as pages 241–250 of this volume.

SURFACE TENSION OF WATER AS A CAUSE OF GEOLOGIC PHENOMENA

BY GEORGE E. LADD

PRELIMINARY NOTE ON THE PLEISTOCENE HISTORY OF PUGET SOUND

BY BAILEY WILLIS

MODIFIED DRIFT IN SAINT PAUL, MINNESOTA

BY WARREN UPHAM

The paper is printed as pages 183–196 of this volume.

NOTE ON PLASTICITY OF GLACIAL ICE

BY ISRAEL C. RUSSELL

An abstract of this paper is published in the Journal of Geology, volume 5, January–February, 1897, pages 104, 105; also in the American Journal of Science.

PHYSICAL BASIS FOR GENERAL GEOLOGIC CORRELATION

BY CHARLES R. KEYES

NOTES ON THE POTSDAM AND LOWER MAGNESIAN FORMATIONS OF WISCONSIN AND MINNESOTA

BY JOSEPH F. JAMES

The President then declared the meeting adjourned.

Register of the Washington Meeting, 1896

The following Fellows were in attendance at the meeting:

F. D. Adams.
T. H. Aldrich.
G. H. Barton.
Florence Bascom.
G. F. Becker.
M. R. Campbell.
W. B. Clark.
Collier Cobb.
Whitman Cross.
H. P. Cushing.
N. H. Darton.
D. T. Day.
J. S. Diller.
G. H. Eldridge.
B. K. Emerson.
S. F. Emmons.
H. L. Fairchild.
G. K. Gilbert.
Arnold Hague.
C. W. Hayes.
Angelo Heilprin.
R. T. Hill.
C. H. Hitchcock.
Arthur Hollick.
J. A. Holmes.
E. H. Hovey.
E. E. Howell.
J. P. Iddings.
Arthur Keith.
J. F. Kemp.
C. R. Keyes.
F. H. Knowlton.
H. B. Kümmell.
G. F. Kunz.
G. E. Ladd.
A. C. Lane.
Joseph Le Conte.
Frank Leverett.
Waldemar Lindgren.
R. G. McConnell.
W J McGee.
E. B. Mathews.
G. P. Merrill.
F. H. Newell.
Edward Orton.
Charles Palache.
L. V. Pirsson.
J. W. Powell.
F. L. Ransome.
H. F. Reid.
Heinrich Ries.
I. C. Russell.
F. W. Sardeson.
Charles Schuchert.
N. S. Shaler.
C. H. Smyth, Jr.
J. E. Spurr.
Joseph Stanley-Brown.
T. W. Stanton.
J. J. Stevenson.
J. A. Taff.
R. S. Tarr.
F. B. Taylor.
H. W. Turner.
M. E. Wadsworth.
C. D. Walcott.
W. H. Weed.
David White.
I. C. White.
H. S. Williams.
Bailey Willis.
J. E. Wolff.

J. B. Woodworth.
G. F. Wright.
W. S. Yeates.
T. W. Vaughan.

Fellows-elect

R. M. Bagg.
E. H. Barbour.
A. C. Spencer.

Total attendance, 79.

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1897

President

Edward Orton, Columbus, Ohio.

Vice-Presidents

J. J. Stevenson, New York, N. Y.

B. K. Emerson, Amherst, Mass.

Secretary

H. L. Fairchild, Rochester, N. Y.

Treasurer

I. C. White, Morgantown, W. Va.

Editor

J. Stanley-Brown, Washington, D. C.

Councillors

(Term expires 1897)

R. W. Ells, Ottawa, Canada.
C. R. Van Hise, Madison, Wis.

(Term expires 1898)

B. K. Emerson, Amherst, Mass.
J. M. Safford, Nashville, Tenn.

(Term expires 1899)

J. S. Diller, Washington, D. C.
W. B. Scott, Princeton, N. J.

FELLOWS, APRIL, 1897

*Indicates Original Fellow (see article III of Constitution)

Frank Dawson Adams, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

Truman H. Aldrich, M. E., Birmingham, Ala. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Philip Argall, 821 Equitable Building, Denver, Col.; Mining Engineer. August, 1896.

George Hall Ashley, M. E., A. M., Ph. D., San Bernardino, Cal. August, 1896.

Harry Foster Bain, M. S., Des Moines, Iowa; Assistant Geologist, Iowa Geological Survey. December, 1895.

Rufus Mather Bagg, A. B., Ph. D., Baltimore, Md.; Assistant in Geology, Johns Hopkins University. December, 1896.

S. Prentiss Baldwin, 1345 Euclid avenue, Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, A. B., Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Alfred E. Barlow, M. A., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, A. M., B. S., Ph. D., Bryn Mawr, Penn.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

* George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

Samuel Walker Beyer, B. Sc., Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Albert S. Bickmore, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. city; Curator of Anthropology in the American Museum of Natural History. December, 1889.

William P. Blake, Tucson, Ariz.; Professor of Geology, Metallurgy, and Mining in University of Arizona. August, 1891.

* John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

* Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.

HENRY P. H. BRUMELL, Ottawa, Canada; Manager of N. A. Graphite and Mining Company. August, 1892.

*SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoölogy in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D., Deadwood, South Dakota; Superintendent Deadwood and Delaware Smelting Company. May, 1889.

ROBERT CHALMERS, Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

*T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

CLARENCE RAYMOND CLAGHORN, B. S., M. E., Vintondale, Pa. August, 1891.

*WILLIAM B. CLARK, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University.

*EDWARD W. CLAYPOLE, D. Sc., Akron, Ohio; Professor of Natural Science in Buchtel College.

JULIUS M. CLEMENTS, B. A., Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

COLLIER COBB, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

ARTHUR P. COLEMAN, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

*THEODORE B. COMSTOCK, Prescott, Ariz.; Mining Engineer.

*FRANCIS W. CRAGIN, B. S., Colorado Springs, Col.; Professor of Geology and Natural History in Colorado College.

*ALBERT R. CRANDALL, A. M., Milton, Wis.

*WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

*HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

T. NELSON DALE, Williamstown, Mass.; Geologist, U. S. Geological Survey, Instructor in Geology, Williams College. December, 1890.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

*WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. WILLIAM DAWSON, LL. D., Montreal, Canada. May, 1889.

DAVID T. DAY, A. B., Ph. D., U. S. Geological Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

Edward V. d'Invilliers, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

* Edwin T. Dumble, Austin, Texas, State Geologist.

Clarence E. Dutton, Major, U. S. A., Ordnance Department, San Antonio, Texas. August, 1891.

* William B. Dwight, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

Charles R. Eastman, A. M., Ph. D., Cambridge, Mass.; Assistant in Paleontology in Harvard University. December, 1895.

* George H. Eldridge, A. B., United States Geological Survey, Washington, D. C.

Robert W. Ells, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

* Benjamin K. Emerson, Ph. D., Amherst, Mass.; Professor in Amherst College.

* Samuel F. Emmons, A. M., E. M., U. S. Geological Survey, Washington, D. C.

John Eyerman, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

Harold W. Fairbanks, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* Herman L. Fairchild, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. Fales, Danville, Kentucky; Professor in Centre College. December, 1888.

Eugene Rudolph Faribault, C. E., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. August, 1891.

Oliver C. Farrington, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

Sandford Fleming, LL. D., Ottawa, Canada; Civil Engineer. August, 1893.

William M. Fontaine, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* Persifor Frazer, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* Homer T. Fuller, Ph. D., Springfield, Mo.; President of Drury College.

Henry Stewart Gane, A. B., Ph. D., Washington, D. C.; Assistant Geologist United States Geological Survey. December, 1896.

Henry Gannett, S. B., A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* Grove K. Gilbert, A. M., United States Geological Survey, Washington, D. C.

Adam Capen Gill, A. B., Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

Charles H. Gordon, M. S., Beloit, Wis. August, 1893.

Ulysses Sherman Grant, Ph. D., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota. December, 1890.

William Stukeley Gresley, Erie, Pa.; Mining Engineer. December, 1893.

George P. Grimsley, M. A., Ph. D., Topeka, Kan.; Professor of Geology in Washburn College. August, 1895.

Leon S. Griswold, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

Frederick P. Gulliver, A. M., 1686 Cambridge St., Cambridge, Mass. August, 1895.

* William F. E. Gurley, Springfield, Ill.

Arnold Hague, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

*James Hall, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

Henry G. Hanks, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

John B. Hastings, M. E., 2222 Second Ave., Spokane, Wash. May, 1889.

John B. Hatcher, Ph. B., Princeton, N. J.; Assistant in Geology, College of New Jersey. August, 1895.

*Erasmus Haworth, Ph. D., Lawrence, Kan.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

*Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Col. August, 1894.

*Charles H. Hitchcock, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, B. Sc., Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia University, New York; Instructor in Geology. August, 1893.

*Joseph A. Holmes, Chapel Hill, N. C.; State Geologist and Professor of Geology in University of North Carolina.

Thomas C. Hopkins, A. M., State College, Center county, Pa. December, 1894.

*Jedediah Hotchkiss, 346 E. Beverly St., Staunton, Va.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city, Assistant Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

*Edwin E. Howell, A. M., 612 17th St. N. W., Washington, D. C.

Lucius L. Hubbard, A. B., LL. B., Ph. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

*Alpheus Hyatt, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

Elfric D. Ingall, Geological Survey Office, Ottawa, Canada; in charge of Mineral Statistics and Mines. August, 1894.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. December, 1888.

Robert T. Jackson, S. B., S. D., 33 Gloucester St., Boston, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

* Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

* James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, A. M., Ph. D., Jefferson City, Missouri; State Geologist. August, 1890.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist U. S. Geological Survey. May, 1889.

Henry B. Kümmel, A. M., Ph. D., Lewis Institute, Chicago, Ill.; Assistant Professor of Physiography. December, 1895.

* George F. Kunz, care of Tiffany & Co., 15 Union Square, New York city.

Ralph D. Lacoe, Pittston, Pa. December, 1889.

George Edgar Ladd, A. B., A. M., Atlanta, Ga.; Assistant Geologist, Geological Survey of Georgia. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

Lawrence M. Lambé, Ottawa, Canada; Artist and Assistant in Paleontology, Geological Survey of Canada. August, 1890.

Alfred C. Lane, Ph. D., Houghton, Mich.; Assistant State Geologist. December, 1889.

Daniel W. Langton, Ph. D., 94 Bayard Ave., Princeton, N. J.; Mining Engineer. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

* Joseph Le Conte, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

* J. Peter Lesley, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

Frank Leverett, B. S., Denmark, Iowa; Assistant U. S. Geological Survey. August, 1890.

Waldemar Lindgren, U. S. Geological Survey, Washington, D. C. August, 1890.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. S., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

Thomas H. Macbride, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

Henry McCalley, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

Richard G. McConnell, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

* W J McGee, Washington, D. C.; Bureau of North American Ethnology.

William McInnes, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Oliver Marcy, LL. D., Evanston, Cook Co., Ill.; Professor of Natural History in Northwestern University. May, 1889.

Othniel C. Marsh, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale University. May, 1889.

Vernon F. Marsters, A. B., Bloomington, Ind.; Associate Professor of Geology in Indiana State University. August, 1892.

Edward B. Mathews, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. Mell, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*Frederick J. H. Merrill, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

George P. Merrill, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.

Thomas F. Moses, M. D., Urbana, Ohio. May, 1889.

*Frank L. Nason, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

*Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.

Frederick H. Newell, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.

William H. Norton, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Frankfort, Ky.; State Mine Inspector of Kentucky. August, 1894.

Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.

*Edward Orton, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

*Amos O. Osborn, Waterville, Oneida Co., N. Y.

Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1894.

*Horace B. Patton, Ph. D., Golden, Col.; Professor of Geology and Mineralogy in Colorado School of Mines.

Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.

Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.

*William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology and Mining Engineering in Michigan University.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.

*Franklin Platt, 1617 Chestnut St., Philadelphia, Pa.

*Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.

John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.

William B. Potter, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.

*John W. Powell, Bureau of Ethnology, Washington, D. C.

*Charles S. Prosser, M. S., Schenectady, N. Y.; Professor of Geology in Union University.

*Raphael Pumpelly, U. S. Geological Survey, Newport, R. I.

Frederick Leslie Ransome, Ph. D., University Museum, Cambridge, Mass.; Instructor in Mineralogy and Petrography, Harvard University. August, 1895.

Harry Fielding Reid, Ph. D., Johns Hopkins University, Baltimore, Md. December, 1892.

William North Rice, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Heinrich Ries, A. M., Ph. B., Columbia University, New York city; Assistant in Mineralogy. December, 1893.

Charles W. Rolfe, M. S , Urbana, Champaign Co., Ill.; Professor of Geology in University of Illinois. May, 1889.

*Israel C. Russell, M. S., C. E., LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Topeka, Kan. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.

*Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, M. A., Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School. December, 1890.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

James Perrin Smith, M. A., Ph. D., Stanford University, California; Professor of Paleontology, Leland Stanford Jr. University. December, 1893.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, A. M., Ph. D., 1320 Corcoran St., Washington, D. C.

Josiah E. Spurr, A. B., A. M., U. S. Geological Survey, Washington, D. C. December, 1894.

JOSEPH STANLEY-BROWN, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

TIMOTHY WILLIAM STANTON, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

* JOHN J. STEVENSON, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

JOSEPH A. TAFF, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

RALPH S. TARR, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

* ASA SCOTT TIFFANY, 901 West Fifth St., Davenport, Iowa.

* JAMES E. TODD, A. M., Vermillion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* HENRY W. TURNER, B. S., U. S. Geological Survey, Washington, D. C.

JOSEPH B. TYRRELL, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

* WARREN UPHAM, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

* CHARLES R. VAN HISE, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.

THOMAS WAYLAND VAUGHAN, B. S., A. B., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

* ANTHONY W. VOGDES, Fort Wadsworth, Staten Island, N. Y.; Captain Fifth Artillery, U. S. Army.

* MARSHMAN E. WADSWORTH, Ph. D., Houghton, Mich.; State Geologist; President of Michigan Mining School.

* CHARLES D. WALCOTT, U. S. National Museum, Washington, D. C.; Director U. S. Geological Survey.

HENRY STEPHENS WASHINGTON, B. A., M. A., Ph. D., Locust, Monmouth county, N. J. August, 1896.

WALTER H. WEED, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

LEWIS G. WESTGATE, 1303 Chicago Ave., Evanston, Ill. August, 1894.

THOMAS C. WESTON, Ottawa, Canada. August, 1893.

DAVID WHITE, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.

* CHARLES A. WHITE, M. D., U. S. National Museum, Washington, D. C.; Paleontologist, U. S. Geological Survey.

JOSEPH FREDERICK WHITEAVES, Ottawa, Canada; Paleontologist and Assistant Director, Geological Survey of Canada. December, 1892.

* ROBERT P. WHITFIELD, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

* EDWARD H. WILLIAMS, JR., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* HENRY S. WILLIAMS, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889.

* HORACE VAUGHN WINCHELL, 1306 S. E. 7th St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

*Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*Arthur Winslow, B. S., care of Missouri, Kansas and Texas Trust Company, Kansas City, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Jay B. Woodworth, B. S., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, A. B., Ph. B., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Georgia. August, 1894.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
*Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1896.
*Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Joseph F. James, M. S. Died March 29, 1897.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Richard Owen, LL. D. Died March 24, 1890.
Charles Wachsmuth. Died February 7, 1896.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died November 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.

Summary

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ACCESSIONS TO LIBRARY FROM MARCH, 1896, TO MARCH, 1897

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(*a*) AMERICA

NEW YORK STATE MUSEUM, ALBANY

BOSTON SOCIETY OF NATURAL HISTORY, BOSTON

1026. Proceedings, vol. xxvii, March–Dec., 1896, 14 parts, 330 pages, 26 plates.

MUSEO NACIONAL DE BUENOS AIRES, BUENOS AIRES

1027. Anales, tomo iv (serie 2, t. i), 1895, pp. 1–357, large 8vo.

CHICAGO ACADEMY OF SCIENCES, CHICAGO

1028. Thirty-ninth Annual Report, 1896, 26 pages.
1029. Bulletin no. 1 (Lichen flora, etc.), 50 pages.

FIELD COLUMBIAN MUSEUM, CHICAGO

1030. Publication 11–13, Zoölogical Series, vol. i, nos. 3–5, 1896.
1031. " 14, Report Series, vol. i, no. 2, 1896.
1032. Annual Exchange Catalogue, 1896–'97, 57 pages.

CINCINNATI SOCIETY OF NATURAL HISTORY, CINCINNATI

1033. Journal, vol. xviii, nos. 3, 4, 1895–'96, pp. 105–202.
1034. " " xix, nos. 1, 2, 1896–'97, pp. 1–80.

COLORADO SCIENTIFIC SOCIETY, DENVER

1035. Proceedings, six separate papers, Sept., 1895–Feb., 1897.

NOVA SCOTIAN INSTITUTE OF SCIENCE, HALIFAX

1036. Proceedings and Transactions, vol. ix, part 1–2, 1896, pp. 1–218.

MUSEO DE LA PLATA, LA PLATA

1037. Revista, tomo vii, 1895, part 1, royal 8vo.
1038. Anales, Seccion Zoologica, ii, 1895, pp. 1–32, 3 plates, folio (*Edentates*).
1039. " " " iii, 1895, pp. 1–8, 2 plates, folio (*Hyperoodontes*).

NATURAL HISTORY SOCIETY, MONTREAL

871. Canadian Record of Science, vol. vi, nos. 3–8, 1894–'96, pp. 117–509.
1040. " " " " vii, nos. 1, 2, 1896, pp. 1–28.

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

1043 Bulletin, vol. xxviii, nos. 1–4, 1896, pp. 1–467.

AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK

1044. Bulletin, vol. viii, 1896, pp. 1–327.
1045. Annual Report of the President, etc., 1895, pp. 1–98.

NEW YORK ACADEMY OF SCIENCES, NEW YORK

22. Annals, vol. viii (Index), 1896.
1041. " " ix, nos. 1–5, 1896–'97, pp. 1–284, 17 plates.
1042. Transactions, vol. xv, 1895–'96, pp. 1–366, 18 plates + Catalogue of exhibits, March 26, 1896.

GEOLOGICAL SURVEY OF CANADA, OTTAWA

ROYAL SOCIETY OF CANADA, OTTAWA

ACADEMY OF NATURAL SCIENCES, PHILADELPHIA

1046. Proceedings, vol. 1896, parts i–iii, pp. 1–614.

AMERICAN PHILOSOPHICAL SOCIETY, PHILADELPHIA

1047. Proceedings, vol. xxxv, 1896, nos. 150-152, pp. 1–290.

MUSEO NACIONAL DO RIO DE JANEIRO, RIO DE JANEIRO

CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

956. Proceedings, second series, vol. 5, pt. 2, 1896, pp. 785–1048, plates 76–104.

GEOLOGICAL SURVEY OF NEWFOUNDLAND, ST JOHNS

ACADEMY OF SCIENCE, ST LOUIS

1048. Transactions, vol. ii, 1863–'68, 3 parts, pp. 1–602.
1049. " " iii, 1873–'78, 4 parts, pp. 1–602 + cclxxxvi.
1050. " " iv, 1880-'86, 4 parts, pp. 1–688 + cxxxiv.
1051. " " v, 1888–'92, 2 parts, pp. 1–629.
1052. " " vi, 1892–'95, 18 parts, pp. 1–547.
1053. " " vii, 1895–'97, nos. 1–12, pp. 1–298.
1054. Contributions to Archæology of Missouri, part 1, Pottery, 1880, 30 pages, 24 plates, 4to.
1055. Total Eclipse of Sun, January 1, 1889, 39 pages, 7 plates, 4to.

COMMISSAO GEOGRAPHICA E GEOLOGICO, SAO PAULO

NATIONAL GEOGRAPHIC SOCIETY, WASHINGTON

958. National Geographic Magazine, vol. vii, 1896, nos. 4–12, pp. 125–412.
1056. " " " " v, 1893, pp. 1–96.
1057. " " " " viii, 1897, nos. 1–4, pp. 1–128.

LIBRARY OF CONGRESS, WASHINGTON

SMITHSONIAN INSTITUTION, WASHINGTON

1073. Report, 1894, 770 pages.

UNITED STATES GEOLOGICAL SURVEY, WASHINGTON

1058. Fifteenth Annual Report, 1893–'94, pp. 1–755.
1059. Sixteenth Annual Report, 1894–'95, part i, Director's report, etc., 910 pages.
1060. Sixteenth Annual Report, 1894–'95, part ii, Economic, 598 pages.
1061. Sixteenth Annual Report, 1894–'95, part iii, Mineral resources, metallic products, 646 pages.
1062. Sixteenth Annual Report, 1894–'95, part iv, Mineral resources, non-metallic products, 735 pages.
1063–1066. Bulletins, nos. 123–126.
1067–1068. " " 128, 129.
1069–1072. " " 131–134.

UNITED STATES NATIONAL MUSEUM, WASHINGTON

(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

1074–1081. Zeitschrift, band i (1849)–viii.
1082. " " ix, heft 1, 3, 4 (heft 2 missing).
1083–1089. " " x–xvi (band xvii–xxiii missing).
1090–1113. " " xiv–xlvii.
1114. " " xlviii, heft 1–3.

KONIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

1204. Jahrbuch, band xv, 1894.

GEOGRAPHISCHEN GESELLSCHAFT, BERNE

1115. Jahresbericht xiv, 1895, heft i, ii.

R. ACCADEMIA DELLE SCIENZE DELL' ISTITUTO DI BOLOGNA, BOLOGNA

1116. Memorie, serie v, tomo iv, 1894, pp. 1–380, 4to.

ACADÉMIE ROYALE DES SCIENCES, BRUSSELS

SOCIÉTÉ BELGE DE GEOLOGIE DE PALEONTOLOGIE ET D'HYDROLOGIE, BRUSSELS

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