

New York State Education Department

NEW YORK STATE MUSEUM

64th ANNUAL REPORT

1910

In 2 volumes

VOLUME I

REPORT OF THE DIRECTOR 1910

AND

APPENDIX



TRANSMITTED TO THE LEGISLATURE JANUARY 30, 1911

ALBANY

UNIVERSITY OF THE STATE OF NEW YORK

1912

STATE OF NEW YORK
EDUCATION DEPARTMENT

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STATE OF NEW YORK

No. 55

IN SENATE

JANUARY 30, 1911

64th ANNUAL REPORT

OF THE

NEW YORK STATE MUSEUM

VOLUME I

To the Legislature of the State of New York

We have the honor to submit herewith, pursuant to law, as the 64th Annual Report of the New York State Museum, the report of the Director, including the reports of the State Geologist and State Paleontologist, and the reports of the State Entomologist and the State Botanist, with appendixes.

ST CLAIR MCKELWAY

Vice Chancellor of the University

ANDREW S. DRAPER

Commissioner of Education

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Education Department Bulletin

Published fortnightly by the University of the State of New York

Entered as second-class matter June 24, 1908, at the Post Office at Albany, N. Y., under the act of July 16, 1894

No. 493

ALBANY, N. Y.

APRIL 15, 1911

New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 149

SEVENTH REPORT OF THE DIRECTOR OF THE SCIENCE DIVISION

INCLUDING THE

64TH REPORT OF THE STATE MUSEUM, THE 30TH REPORT
OF THE STATE GEOLOGIST, AND THE REPORT OF
THE STATE PALEONTOLOGIST FOR 1910

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New York State Education Department

Science Division, January 16, 1911

Hon. Andrew S. Draper LL.D.

Commissioner of Education

SIR: I have the honor to transmit herewith for publication as a bulletin of the State Museum, the annual report of the Director of the Science Division for the fiscal year ending September 30, 1910.

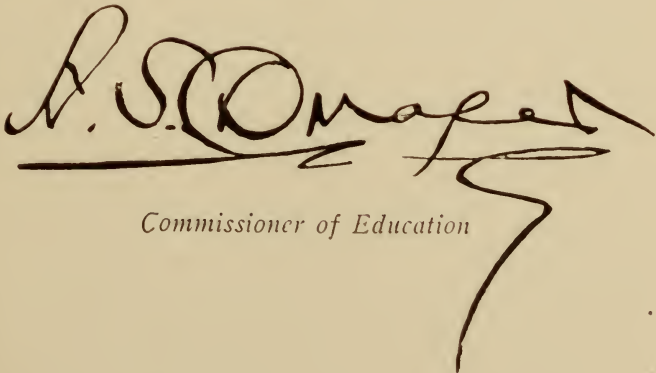
Very respectfully

JOHN M. CLARKE

Director

STATE OF NEW YORK
EDUCATION DEPARTMENT
COMMISSIONER'S ROOM

Approved for publication this 18th day of January 1911

A large, stylized handwritten signature in black ink, reading "A. S. Draper". The signature is written in a cursive style with a prominent horizontal line underneath the name. A long, sweeping flourish extends from the bottom right of the signature.

Commissioner of Education

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JOHN M. CLARKE, Director

Museum Bulletin 149

SEVENTH REPORT OF THE DIRECTOR OF THE SCIENCE DIVISION

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64th REPORT OF THE STATE MUSEUM, THE 30th REPORT OF
THE STATE GEOLOGIST, AND THE REPORT OF THE STATE
PALEONTOLOGIST FOR 1910

INTRODUCTION

This report covers all divisions of the scientific work under the charge of the Education Department and concerns the progress made therein during the fiscal year 1909-10. It constitutes the 64th annual report of the State Museum and is introductory to all the scientific memoirs, bulletins and other publications issued from this office during the year mentioned.

Under the action of the Regents of the University (April 26, 1904) the work of the Science Division is "under the immediate supervision of the Commissioner of Education," and the advisory committee of the Board of Regents of the University having the affairs of this division in charge are the Honorables: T. Guilford Smith LL.D., Buffalo; Daniel Beach LL.D., Watkins; Lucian L. Shedden LL.D., Plattsburg.

The subjects to be presented in this report are considered under the following chapters:

- I Condition of the State Museum
- II Report on the Geological Survey
- III Report of the State Botanist
- IV Report of the State Entomologist

- V Report on the Zoology section
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I

CONDITION OF THE SCIENTIFIC COLLECTIONS

Since my last report few changes have been necessitated in the location of the museum collections, except for continued progress in the transference of the scientific materials to the storage house and the general preparation of the collections for transfer to and exhibition in new quarters. This work has involved much careful and expert labor in all sections, the selection of choice exhibits, the preparation of groups, models and charts, and in reasonable measure the expenditure of money for expert assistance which the staff can not give. Much of the time which has before been given to the work of scientific research has of necessity been directed into the channels mentioned.

In my report of last year I stated the location of the collections in eight different places in the city of Albany, in addition to some valuable material in storage in the city of Rochester. These locations remain unchanged. Considerable valuable accessions to all departments of the museum have been made during the year. Their character is given under chapter IX of this report.

II

REPORT ON THE GEOLOGICAL SURVEY

AREAL GEOLOGY

In the progress of the survey directed toward the execution of the geological map of the State on the topographic scale of 1 mile to 1 inch, a considerable number of topographic quadrangles have been completed and published, with full explanatory details of geological structure. In addition to the completed quadrangles a variety of special maps have been issued in connection with particular geological problems, some of the older of these maps being

on such geographic base of approximate accuracy as was best available, but all special maps of later years, whether they have covered limited areas, completed county areas or a series of counties, have been based on the topographic unit.

A list of all geologic maps of the State, of every description, issued officially or privately, was published in my report for 1908, and the number was there shown to be large, 329 entries being recorded. At least ten items may be added to this number at the present date. I append here a list designed to indicate only the complete quadrangle maps which have been made with special reference to the systematic execution of the State map. In this list the terms starred indicate maps now in press:

Alexandria Bay (Cushing)	Nunda (Clarke & Luther)
Amsterdam (Prosser & Cumings)	Olean (Glenn)
Auburn (Luther)	Ontario Beach (Hartnagel)
Buffalo (Luther)	Ovid (Luther)
Canandaigua (Clarke & Luther)	Oyster Bay (Woodworth)
Cape Vincent (Ruedemann)	Penn Yan (Luther)
Clayton (Cushing & Ruedemann)	Portage (Clarke & Luther)
Elizabethtown (Kemp)	Port Henry (Kemp & Ruedemann)
Elmira (Clarke & Luther)	Port Leyden (Miller)
Genoa (Luther)	*Poughkeepsie (Gordon)
Grindstone Island (Cushing & Smyth)	Remsen (Miller)
Hammondspport (Luther)	Rochester (Hartnagel)
Hempstead (Woodworth)	Salamanca (Glenn)
*Honeoye (Luther)	Theresa (Cushing & Ruedemann)
Little Falls (Cushing)	Tully (Luther)
Long Lake (Cushing)	Watkins (Clarke & Luther)
Mooers (Woodworth)	*Wayland (Luther)
Naples (Clarke & Luther)	

In addition to these, reports have been rendered to the Director on the quadrangles listed below, which are awaiting publication chiefly for completion in certain details:

Batavia	Morrisville
Caledonia	Phelps
Cazenovia	Syracuse
Chittenango	

On the following quadrangles of the topographic map, areal work is now in progress, as indicated by special reference in subsequent pages.

Albion	Lockport	Saratoga
Attica	Medina	Schuylerville
Broadalbin	Mt Marcy	Stamford
Depew	North Creek	Tarrytown
		Utica

Central and western New York. In western New York Mr Luther has been engaged in the resurvey of the Erie and Chautauqua county quadrangles, viz, Eden, Angola, Cherry Creek, Dunkirk and Westfield, to bring the detailed subdivision of the various formations into correspondence with that of the maps already published. The field work on these areas is regarded as practically complete and the maps are now being prepared for publication. As noted last year, work has also been in progress on the *Batavia*, *Attica*, *Depew*, *Albion* and *Medina* quadrangles.

On the Utica quadrangle the work was a completion of that begun the previous summer; the mapping of those parts of the quadrangle then left uncompleted, elaborating the details of those parts covered during the former season, and in carefully collecting the fauna of the region, especially that of the Lowville, Black River and Trenton limestones along the West Canada creek. Within the quadrangle there outcrop representatives of all formations of the Lower and Upper Siluric systems with the exception of the Chazy. Thus the Little Falls, Lowville, Black River, Trenton, Utica, Lorraine, Oneida-Medina, Clinton, Salina and Manlius are represented. As the dip is southwest the lower formations outcrop only in the northeastern corner of the area, while the uppermost formations are found only in the southwestern portion of the region. In many sections the glacial deposits are heavy and interfere greatly in working out the contacts.

The extreme northeastern section, being all that part on the quadrangle northeast of the West Canada creek, is covered with sand terraces of sufficient thickness to conceal all the bedrock of the region, except for outcrops of the Little Falls dolomite along Cold brook south of the village of the same name, and a few other outcrops on Buck hill, directly north. The upper 300 feet of this hill is Trenton limestone with the Black River and Lowville limestones occurring between it and the Little Falls dolomite. A mile and a half below the village of Poland, the Little Falls dolomite occurs, but a short distance farther south West Canada creek is underlain by the Lowville limestone, which continues nearly to Newport where the Little Falls again appears at the surface, due

to the unconformity existing between these two formations. The region south of Cold brook and east of West Canada creek seems distinctly different from the rest of the region, and extends over as far as White creek on the Little Falls quadrangle, where the only outcrop in the whole region is a Lowville limestone quarry. The Trenton and Dolgeville members are not seen and there seems to be little evidence to indicate their presence except for a possible indefinite small thickness of Trenton.

The southwestern bank of the West Canada creek is markedly different from the other bank. It is steep and from a point about a mile and a half below Poland gives a continuous outcrop nearly to Newport. North of this point the steep bank is made up of glacial material until a point about two miles above Poland is reached, where the Trenton outcrops by the bridge.

Below Poland there are about 31 feet of Lowville in the bank and in the hills immediately bordering the creek. Above this occur from 7 to 9 feet of Black River limestone, which in general forms the top of the lowest terrace. Upon this rests the Trenton limestone with a thickness of about 200 feet forming the bordering hills. These are covered with sand, an underlying boulder clay appearing in places and commonly covering contacts. Where the country flattens out on the top of the hills the Utica shale appears and covers all the region to the west and south as far as the Mohawk river and some distance beyond. To the west along Nine Mile creek at a point just west of South Trenton a low fold brings the Trenton up about a foot above the surface of the creek and shows the Trenton-Utica contact. The Trenton also shows at two other points farther downstream, the region between being shales.

Southwest of Newport is a ridge of high hills which continues to the west, becoming lower and broader. This ridge is capped with the sandy Lorraine shales, having a thickness of 340 feet at the eastern end. Since there are but 440 feet of these shales occurring south of the Mohawk between the Utica below and the Oneida conglomerate above, it might seem probable that there existed at one time on the top of these hills an extra hundred feet or more of the Lorraine shales with a cap of the resistant Oneida conglomerate, thereby explaining the presence of this very prominent and dominant ridge, which seems to have been an important factor in determining the preglacial physiography of the region.

The thickness of the Utica shale is about 600 feet. This would seem to indicate that the rock floor of the Mohawk valley in this section might be Trenton limestone.

To the south of the Mohawk a narrow belt of Utica shale occurs up to an elevation of about 550 feet. Above this the black Utica shale changes into the gray Lorraine shale having a thickness of about 440 feet, and forming the northern slope of the southern escarpment. At an elevation of about 1000 feet come the northern outcropping edges of the Oneida conglomerate. This contains also shale and gray sandstone layers, often cross-bedded with intervening layers of fissile gray shales. In all there are about 100 feet of this formation.

Above the Oneida are 110 feet of Clinton shales, limestones, sandstones, and red hematite ore. The shales, limestones, and ore form the lower part and change upward into sandstone.

The Clinton is covered with 200 feet or more of red Salina shales. The lower contact was found in the central southern part of the quadrangle and the upper contact in the southwestern portion. These are the only two outcrops, the region between being covered with thick drift. Above the red Salina, in the extreme southwestern portion only, were found 10 feet of green Salina shales and these were overlain in turn by gray, fissile, shaly limestone and greenish shales aggregating over 70 feet in thickness. The upper limit was covered. One of the bottom layers contained abundant crystal cavities in a black shaly limestone or calcareous shale. The middle portion in one place was a mass of sun cracks, indicating the conditions of formation.

The top of the Salina is covered with two different boulder clays and in the ridge beginning south of Norwich Corners is found the Manlius. Just beyond the southern edge of the map are the well-known Litchfield waterline quarries.

Eastern New York. *Saratoga and Schuylerville quadrangles.* The areal survey of the Saratoga region has been carried well toward completion by Messrs Cushing, Miller and Ruedemann. In my last report, on referring to this subject and this region, I indicated the importance of a survey which, in view of the public interest in acquiring the mineral water rights of Saratoga Springs by the State, would take the form not merely of a surface study of the rock outcrops and dislocations but involve a subterranean exploration directed to ascertain the relations of the rock strata to the origin and accumulations of the saline waters and the relation of both to the stores of carbon dioxide. This subterranean investigation would involve an expenditure greater than our appropriations for areal geology will allow. The proposed plan has there-

fore been submitted to the Commissioners of the State Reservation at Saratoga, has met their approbation and, if the means are provided, it may be hoped that the project will be carried into execution.

The Precambrian rocks of the Saratoga and Schuylerville region have received special attention. These consist chiefly of two types, syenites and rather uniform Grenville gneisses. There is but little Grenville limestone. A comparatively thin band of quartzite which locally is strongly graphitic, is worked for graphite at two localities; but the Grenville is mainly a white, or whitish, quartz-feldspar gneiss, with pinkish garnets quite like the rock at Sprakers and on the Little Falls quadrangle, and a very common rock in the Grenville of the southern Adirondack border. The syenite cuts through it in a series of comparatively small intrusions. In character and in variations much of the syenite is very like the rock at Little Falls. It becomes a coarse augen gneiss at its margins.

There are a few diabase dikes which make up in size what they lack in number. The great dike quarried just north of Saratoga for road metal was followed northward for 12 miles to the edge of the quadrangle, and is capable of furnishing an enormous amount of road material.

The Northumberland volcanic plug on the Schuylerville sheet was visited and carefully studied. Quarrying has rendered it much easier of study than was the case ten years ago when Doctor Woodworth first described it. It has been faulted and a tremendous shear zone cleaves it diagonally from base to summit. The nature of this shear zone leads to the belief that the rock must have been under considerable load when the shearing took place, and that the load has since been worn away. Hence a considerable antiquity for the plug is suggested.

It was found necessary for the correlation of the "Hudson River" shales of the Saratoga sheet to investigate first the Frankfort and Utica beds of the Mohawk valley. This work indicates that both the Utica and Frankfort stages consist of two different divisions. The lower one of the Utica shale agrees in its fauna with the lower third of the Martinsburg shale of the Appalachian basin and is undoubtedly of upper Trenton age. It is therefore separated from the typical Utica stage as *Canajoharie shale*. This formation, to which much of the shale along the Hudson and in Albany and Saratoga counties belongs, rapidly thins out westward and does not reach the meridian of Utica. In the lower Mohawk valley the remaining upper division of the Utica shale also differs

somewhat in its faunal aspect from the beds in the neighborhood of Utica, but retains about the same thickness and lithological character.

The Frankfort shale which, from 300 feet at Frankfort swells to 1500 or 1800 feet in the lower Mohawk valley, has very unexpectedly furnished faunules at many horizons, although it had hitherto been considered as practically barren. Altogether about seventy species have been obtained, among them an entirely new eurypterid faunule, the first Lower Siluric eurypterid fauna known, except for the two fragments each of *Echinognathus* and *Megalograptus*. This eurypterid fauna was found to range through the entire thickness of the Frankfort shale with the exception of several hundred feet at the top exposed at the foot of the Indian Ladder in the Helderbergs, which carry a different fauna. The latter, which will be distinguished as *Indian Ladder beds*, are also characterized by the rapid alternation of shales and thin sandstone with argillaceous limestone beds.

The distribution of the eurypterid fauna in the Frankfort shale is peculiar in that this fauna rapidly disappears westward while the greater proportion of the other fossils continues, but the eurypterids continue westward into the Schoharie reentrant of the Helderberg escarpment. Since the eurypterids are associated with immense masses of seaweeds (*Sphenothallus latifolium* Hall, et al., which have been obtained in very complete specimens, and lend themselves to close study) which also fail in the finer shales to the west, it is inferred that the Eurypterid-Sphenothallus association was restricted to a sinking and rapidly filling "vorland" of the rising Appalachian land to the east, or to the littoral region, while the other Frankfort fauna was spreading farther offshore. The graptolite, brachiopod, trilobite and mollusk elements of the Frankfort fauna prove that the latter is to be regarded as a direct continuation of the Utica beds as has been generally done. The Lorraine beds have not been found in the Mohawk valley.

During the investigation of the Frankfort shale in the Cobleskill region, evidence was also obtained showing that the Brayman shale, which formerly was referred to the Clinton and later correlated with the Salina, is most probably of Lower Siluric age.

Adirondacks. Field work has been carried on by Professor Miller in the *North Creek* quadrangle where the territory, though fairly rugged, is well supplied with roads and outcrops are generally numerous so that very detailed observation has been possible.

About three-fourths of the quadrangle has been covered and, thus far, the rocks are all of Precambrian age. A well-defined and heretofore unnoted outlier of Paleozoic rock (Potsdam sandstone and Little Falls dolomite) has been found just south of the sheet and one mile west of High Street village.

The Grenville formation is present to an unusual extent, making up nearly 50 per cent of the area so far studied. Limestone occurs in abundance and with it is associated an extensive mass of hornblende gneiss. Other common Grenville rocks are: quartzites, gray garnet gneisses, white feldspar gneisses, and graphitic schists. Almost without exception the Grenville occupies the valleys.

No less than four ages of igneous rocks — all younger than the Grenville — have been observed. Of these the syenites and associated rocks are by far most prominent. The greenish gray rather quartzose syenite often grades into a pink medium-grained biotite granite on one hand and into a gray coarse-grained, very porphyritic granite on the other. These syenites and granites have broken through the Grenville in a very irregular manner so that the geologic map will present a decided "patchwork" effect.

Large dikes or small bosses of gabbro cut both the Grenville and the syenite-granite series. No less than forty of these dikes have already been mapped and the rocks show but little sign of metamorphism. Pegmatite dikes are common and they have been found cutting the gabbros in many places.

The youngest rocks of the district are in the form of diabase dikes which are known to cut all the other formations, even the pegmatites. The rocks are generally much finer grained and the dikes are fewer in number and usually smaller than the gabbro.

The region has been subjected to rather extensive normal faulting and a number of these faults have been mapped. The strike of the faults varies from northeast-southwest to northwest-southeast.

The topography is almost wholly dependent upon rock character and structure. Because of several favoring conditions, exfoliation domes (syenite or granite) form a striking feature of the landscape.

The glacial phenomena are also of interest. Many glacial striae have been observed and in no case do they vary more than twenty degrees from due north and south. A fine example of a glacial lake (Lake Warrensburg) formerly covered all the lowland area around Warrensburg and had arms which extended for several miles up both the Hudson and the Schroon rivers. Another con-

siderable lake existed in the vicinity of Johnsbury. It has also been quite definitely proved that, before the glacial epoch, the Hudson river did not flow southward across the Luzerne region, but that its course was past Warrensburg and the south end of Lake George and thence toward Glens Falls.

Work on the *Mt Marcy* quadrangle has been inaugurated by Professor Kemp who with Doctor Ruedemann recently issued a report on the Elizabethtown sheet. *Mt Marcy* lies next west and is a region of complicated and rough topography. So far as this field has been investigated there appears to be at the north a complicated mixture of the anorthosites and Grenville strata, especially the limestones of the latter. The region has afforded interesting contact zones with the characteristic lime silicates, wollastonite, garnet, pyroxene and the like.

Professor Hudson, who has been working as opportunity afforded on the special survey of *Valcour island*, reports progress in the execution of a topographic map with 1 meter contours and in the solution of many problems which have arisen most unexpectedly from the study of the latter unit — problems bearing on the greater history of Lake Champlain and its origin, on the special effectiveness of minor physical forces and on the life history of the fossil-bearing formations of which the island is constituted.

Southeastern New York. The survey of the *Poughkeepsie* quadrangle has been carried to completion by Professor Gordon and his report and map are now on the press.

In the *Highlands* district Doctor Berkey has studied three typical areas with special care and with laboratory aids in an effort to establish satisfactory subdivisions of the older crystalline series. It has been found possible to determine the sedimentary origin of an occasional rock and the igneous origin of certain others beyond reasonable doubt. Many of the strongly foliated gneisses are, however, practically indeterminable. It seems desirable to make these distinctions in the areal work of the Highlands wherever the types are developed on large enough scale. Chemical and microscopic studies have been made in connection with this work, and a special study is being made of the Cortlandt series in still greater detail.

Portions of the *Tarrytown* quadrangle and its geology have been reviewed with the intention of securing conformity with the later interpretations of formational relationships. The original field work on that quadrangle was done before some of these relations

had been worked out. The matter referring to the Tarrytown district is being put into form for publication.

In previous reports reference has been made to a cooperative undertaking with the New York City Board of Water Supply in the elucidation of geological problems encountered in explorations along the line of the Catskill Aqueduct. Our representative in this work has been Doctor Berkey, whose report on studies from the earlier exploratory work *On the Geology of the New York City (Catskill) Aqueduct* is now printing. During the past year great progress has been made in actual construction in this important engineering work. Many shafts and tunnels penetrate portions of formations that have never before been exposed to observation. The opportunities for collecting data of much value in a study of this region have been exceptional, but immediate advantage must be taken of them.

A four-mile tunnel is almost completed beneath the Rondout valley, and similar ones, penetrating the Shawangunk mountains and beneath the Wallkill valley, have reached about the same stage. Smaller parts are finished at several other points farther south. Interpretations that had been made from the evidence of surface outcrops and drill borings are now being exposed to direct comparison with the facts revealed in the underground workings. These later and final results will be made available in some suitable form upon the completion of the work.

Exploration is still in progress on the Hudson river between Storm King and Breakneck mountains. The deepest boring in the middle of the river has penetrated river silts and drift filling to a depth of 751 feet below the river level without reaching bedrock. Inclined borings have been made from shafts at either side of the river and have advanced far enough to cross beneath the center of the channel. Each boring is about 1500 feet long and a survey of the holes indicates that they cross at a depth of approximately 950 feet below river level. It is certain therefore that the preglacial or glacial channel bottom lies somewhere between -751 and -950 feet. The drill cores indicate sound rock throughout.

The depths to which water circulation has accomplished extensive solution or decay is a related matter of special interest at several other points. In the Rondout valley the pressure tunnel has encountered several large clay seams, several feet wide, at a depth of 150 feet below present sea level. These seams are clearly fillings of former solution channels in the Helderberg limestones. They indi-

cate ready circulation with tendency to cave development at a depth much below present action of this kind, and appear to give additional support to the belief in former continental elevation of considerable amount. In New York city exploratory borings have shown that decayed rock occurs in zones or streaks to depths reaching in rare instances to more than 500 feet. In the immediate vicinity fairly sound rock may be found. A study of the distribution of these decayed portions leads to the conclusion that they always follow structural weaknesses of the rock, either a contact, or a fault, or a crust zone, and that the decay to such extreme depth has been caused by a ready circulation of surface waters along those lines at a time when the continent stood at an elevation more favorable for such movements than the present. Incidentally their frequent occurrence throws some light on the question of prevalence of faulting within the New York city area.

A fundamental problem of the geology of southeastern New York has to do with the character and history of the basal gneiss, or the Fordham gneiss series, and the relation of overlying beds to it. The tunnels now in process of construction will penetrate some of those portions seldom reached and will add materially to the data bearing upon this question. Exploratory borings have already given indisputable proof of the existence of many thin interbedded limestone layers within the banded Fordham gneiss series proper. Nearly all of those discovered in this way lie beneath a heavy cover of drift and could not have been found except by drilling. This relation of certain limestone beds has been pointed out in former reports, but until recently the abundance of these interbeds has not been appreciated. Surface weathering tends to obscure them on the outcrops and this accounts in part for the difficulty of finding many satisfactory cases in field work.

Further study of the rock floor of Manhattan and Brooklyn indicates that the heavy drift cover has materially altered the outlines of Manhattan island and has displaced some of its streams and connecting channels. The East river, shifted out of its former course by the drift, is one of these. A drift-filled valley through the lower east side in southern Manhattan is more than 100 feet deeper than the present East river channel.

Doctor Berkey's investigations of the problems which have been brought into the foreground by these various engineering operations have been supplemented by the work of other geologists in the city of New York upon problems of immediate local concern. To

Professor Kemp, Doctor Berkey and Doctor Hollick has been assigned the acquisition of such data as will make a satisfactory report on the geology of Greater New York — a work which ought to be of large practical usefulness to architects, engineers and municipal betterments generally in the city of New York.

During the season Doctor Hollick has given his attention especially to the geological structure of *Staten island* both from surface exposures and from the records of underground structure.

Classification of the New York formations. The growth of our knowledge and the refinement of our work has made desirable a published restatement of the classification of the geological formations of the State. It is seven years since the last summary statement of this kind was issued. There are now about 125 names which have been applied to these formations — a bewildering number, but each has a value which requires exact definition for the intelligent appreciation of our geology.

SURFICIAL GEOLOGY

In the northern part of the State, Professors Fairchild and Chadwick have studied the special features of Lake Iroquois and Gilbert gulf.

The Lake Iroquois altitudes and limits in the region are now approximately determined. In the valleys of the large rivers, as the Grass, Raquette, St Regis and Chateaugay, the Lake Iroquois level is indicated by delta sand plains of vast extent which agree in their summit altitudes. The actual head of the easternmost of these deltas, that on the Chateaugay, was examined. Here the boulder and cobble deposits cover considerable area, and with the correlating lake features show a fairly definite altitude for the Iroquois water at 980 feet, taking the railroad tracks at Chateaugay station as 945.

About 3 miles southeast of Russell, on the meridian of Canton, is a series of heavy cobble and gravel bars which have a summit altitude of about 835 feet. The Iroquois plane between Watertown and Chateaugay has a rise of about 2.27 feet per mile, in direction northeast, and reaches Covey gulf, the point of escape, with an altitude of about 1016 feet, or about 36 feet over the head of the present channel. The fall of the lake level from the full-height or Rome level to the Covey gulf level was probably not over 15 or 20 feet. This fall might have been by removal of drift or rock, or down-cutting of the channel.

A recent Canadian survey has marked altitudes about the region of Covey hill and westward beyond Franklin, which helps to give precise figures for the height of the marine waters. The highest well-developed bar about Covey hill is 523 feet, which is 65 feet over the former aneroid figures.

The physical character of shoreline phenomena is alone conclusive argument for the marine origin. Going east from Covey Hill post office, eighteen good bars are noted in the descent of 130 feet, the widest interval being 12 feet. Such uniformity in strength and spacing could not be produced in the fall of glacial lake waters, but it is to be expected in the lifting of the land out of sea-level waters.

The remarkable series of close-set bars were followed westward about Covey hill promontory into New York, having a slow fall in summit altitude. This altitude of the unquestioned marine shore lines along the international boundary brings them into the same plane as the Gilbert gulf beaches in Jefferson and St Lawrence counties and removes any doubt as to the sea-level origin of the latter. The rise of the marine plane from Lafargeville to Franklin, Ont., is a little under 1 foot to the mile.

Professor Chadwick has directed attention to the several heavy delta sand plains lying in height between the Iroquois and the marine levels. These seem to indicate a stand of water too long to represent merely a pause in the rapid down-draining of Iroquois water across the steep face of Covey hill. They suggest some undiscovered complexity in the glacial lake history which requires further study.

In the Mohawk-Hudson region Professor Brigham has directed his observations to the southern limit of the Mohawk glacial lobe and to its relation to the Hudson valley lobe. The designation, Mohawk lobe, is of somewhat indefinite application, because the lobe was a part of the waning ice sheet and there is no boundary so marked by topographic features, glacial or otherwise, as to create a sharply definable stage deserving this name. Certain features, nevertheless, point to a reasonable differentiation of a glacier within the Mohawk valley and overlapping to some distance upon the headwaters region of the Susquehanna.

On the south the place of bifurcation between the Hudson and Mohawk lobes may be confidently placed at the northern end of the bolder development of the Helderberg escarpment, in the Berne quadrangle west and southwest of Altamont. This was inferred from an inspection of the contours of the map and is abun-

dantly borne out in the field. In the southeastern parts of the quadrangle the movement was south. In the northwestern section the direction was nearly west, and in the central and southeastern parts around the village of Berne and toward the hamlet of Connersville, the direction of striae is intermediate. There is a sharp alignment of drumloidal forms in the east and north which does not prevail in the intermediate or southwest direction, pointing to the more prolonged and heavy scorings of the Mohawk and Hudson lobes.

About one and one-half miles west of Altamont the exposed slopes which were subject either to Hudson or Mohawk movements, show interesting striae ranging from s. 10° e. to west. On one surface are striae s. 5° e. crossed by another set having directions s. 30° to 35° w. Another surface has two sets, one s. 5° to 10° w. the other west. These records point to an alternating or conflicting control by the two movements at the very point of differentiation, as determined by the strong northward end of the Helderberg front.

To the westward detailed study is needed. There is, however, a significant development of moraines which may in a general way mark the southwest border of the lobe, and may probably be contemporaneous with the Gloversville moraine. These moraines occur near the headwaters of Cobleskill creek near West Richmondville; along Schenevus creek from its head to its junction with the Susquehanna; along the lower sections of Elk creek valley and Cherry Valley, and along the Susquehanna from Cooperstown to Portlandville. It is significant that a day's drive among the strong hills between Cooperstown and Westford led to the finding of but one locality of striae, showing a remarkably continuous sheeting of thick ground moraine for such topography. As noted by Chamberlain in his early work in central New York, the westward limit of Mohawk movements seems to have been in southern Herkimer county not far from West Winfield and Cedarville. The drumlins and drumlinoids with east by west axes are conspicuous between Richfield Springs and Herkimer.

INDUSTRIAL GEOLOGY

Report on gypsum. As mentioned in my last report, an investigation of the gypsum deposits of the State was undertaken in 1909 with the view of a comprehensive description of these resources which are widely distributed and of growing economic importance.

The investigation has now been brought to completion and its results made available in a bulletin recently issued.

The commercial utilization of the local deposits began about a century ago, but the present mining and manufacturing enterprises which they support may be said to be a development of the last decade. In this brief period the annual outturn of crude gypsum has grown from 50,000 tons to nearly 400,000 tons and, whereas the product was formerly marketed in unmanufactured condition, or at most simply reduced to powder at the mines, it is now mainly converted into calcined plasters that require refined mechanical treatment and correspondingly extensive plants. With the expansion of the trade many changes have taken place in the mining field, particularly the opening of very productive territory in the western part of the State where the gypsum is better adapted for calcination and the adoption of improved methods of extraction. The whole industry, thus, has taken on a new phase which has not heretofore received adequate attention.

Review of mines and quarries. The statistical canvass of the mines and quarries of the State conducted by this office, showed that a general improvement in the industries was manifest during the past year. The aggregate output of the mineral materials reached a value of \$34,914,034, a gain of more than \$5,000,000 over the total value reported for 1908. Though it fell somewhat short of the record for the industries, it evidenced their strong position after a period of very great depression, and their capacity for further growth. About thirty-five different products were represented in the total. The largest items, naturally, were clay and stone materials, though iron ores, cement, salt, natural gas, petroleum, gypsum and talc were produced in important quantities. It may be noted that the products are valued for the purposes of the statistical report in their crude form, so that the totals are not to be regarded as a full measure of the contributions made by the mineral industries as a whole.

Field work. Though no extended field work has been in progress within the past year, occasional trips were made, as opportunity offered, to observe new developments or discoveries in certain districts, of which there was need for definite information.

In southeastern New York some of the old iron mines of Columbia and Dutchess counties were visited and it is hoped in the near future to give the deposits of this section further study. The district is of great historical interest, having supplied the first ores used for iron manufacture in the State and long holding a promi-

ment place among the mining regions of the country. There has been practically no production for the last twenty years; but with the recent improvements in the conditions surrounding the iron industry of the East, a revival of mining in this section seems not unlikely. No detailed study of the geology and ore occurrences is available at present; the literature is limited to the brief reports by Putnam and Smock which are mainly descriptive of the individual mining operations as conducted at the time of their visits (more than twenty years ago) and to one or two brief articles since contributed to the scientific press.

Recent exploratory work in the Adirondacks has added to our knowledge of the magnetic ores of that region, in particular those of Mineville and the vicinity of Arnold Hill. In the latter district some apparently extensive bodies of magnetite that had escaped the attention of mining companies formerly active there, have been uncovered. The explorations are to be continued until the importance of the deposits may be accurately measured.

SEISMOLOGICAL STATION

The Bosch-Omori pendulums which are installed in the basement of the State Museum have been maintained in good working order throughout the year. Such interruptions as occurred were necessary to the proper care of the instruments. In their present surroundings where the air becomes very moist during the summer months they are very liable to injury from rust and consequently require frequent attention.

The equipment has been improved by the addition of a large clock which is regulated every hour by standard time received over the Western Union wire. Hitherto the connection of the instrumental time clock could be made only by indirect comparison with the local service so that there was always an element of error in the records, amounting perhaps to as much as a minute. With the present arrangement the error can not exceed a few seconds at most, which is well within the limits of accuracy for registration in machines of this design.

The number of earthquakes recorded at Albany for the year ending September 30, 1910, was 23, as compared with 19 in the preceding year. A total of 77 disturbances has been observed since the instruments were installed in March 1906. Despite the fact that the records indicated a relatively high frequency for the year, in excess of that hitherto noted at this station, there were very few macroseisms and only a small number which afforded well-defined

records with the phases so differentiated as to be of service for purposes of calculation. For the most part the shocks showed weak movements and were of uncertain origin. In agreement with these observations attention may be called to the comparatively few destructive earthquakes that have been reported by the press, whereas the few preceding years were memorable for the number and violence of such disturbances in various parts of the world.

An exchange of records has been maintained with other stations which are so situated as to make a comparison of the data mutually desirable. Brief notes on the observations have also been communicated to the press from time to time.

Particulars of the year's records are here given. For their interpretation it may be said that the Albany station is equipped with two Bosch-Omori horizontal pendulums, one set along the meridian and the other east-west. The weight of each pendulum, including arm, is 11.283 kilograms and the distance of center of gravity from rotating axis is 84.6 centimeters. Their period is maintained between the limits of 25 and 30 seconds. A multiplying ratio of 10 is used. There is no artificial damping. Albany is situated in latitude n. $42^{\circ} 39' 6''$, longitude w. $73^{\circ} 45' 18''$. The base of the instruments lies 21 meters above sea level.

RECORD OF EARTHQUAKES AT ALBANY STATION, OCTOBER 1, 1909 TO
SEPTEMBER 30, 1910
Standard time

DATE	Beginning preliminaries	Beginning principal part	Maximum	End	Maximum amplitude
1909					
October 20.....	h. m. 7 06 P. M.	h. m. 7 32 P. M.	h. m. 7 41 P. M.	h. m. 8 30 P. M.	mm. 2
October 31.....	5 30 A. M.	5 45 A. M.	5 45 A. M.	6 55 A. M.	3
November 10.....	1 38 A. M.		1 48 A. M.	2 40 A. M.	2
December 9.....		11 46 A. M.		1 + A. M.	1
1910					
January 1.....	6 08 A. M.	6 16 A. M.	6 17 A. M.	8 00 A. M.	20
January 22.....	3 57 A. M.	4 08 A. M.	4 10 A. M.	5 + A. M.	30
January 23.....	2 02 P. M.			3 + P. M.	2
February 28.....	4 16 P. M.	4 29 P. M.	4 31 P. M.	5 30 P. M.	1½
March 30.....	12 39 P. M.	1 01 P. M.	1 04 P. M.	1 45 P. M.	1
March 31.....	2 07 P. M.	2 18 P. M.	2 20 P. M.		
May 4.....	7 40 P. M.	7 48 P. M.	7 53 P. M.	8 + P. M.	1
May 13.....	3 15 A. M.	3 34 A. M.	3 35 A. M.	5 00 A. M.	3
May 20.....	7 16 A. M.	7 24 A. M.		8 + A. M.	1½
May 31.....	12 02 A. M.	12 16 A. M.	12 18 A. M.	12 50 A. M.	1½
June 16.....	1 50 A. M.		2 09 A. M.	4 + A. M.	6
June 17.....	12 14 P. M.		12 29 P. M.	1 20 P. M.	
June 29.....	3 49 A. M.		3 55 A. M.	4 25 A. M.	½
June 29.....	6 38 A. M.	6 46 A. M.	6 49 A. M.	7 30 A. M.	1
July 3.....	4 28 A. M.			4 40 A. M.	½
July 6.....	11 52 P. M.	11 59 P. M.	12 00 P. M.	12 45 P. M.	3
August 4.....	8 39 P. M.	8 51 P. M.	8 52 P. M.	9 40 P. M.	20
August 11.....	11 36 A. M.	11 45 A. M.	11 46 A. M.	12 27 P. M.	2
September 23.....	10 38 P. M.	10 53 P. M.	10 54 P. M.	11 30 P. M.	1

October 20. The record of a distant earthquake, probably originating 5000 miles or more away, but not identified with any known disturbance on land.

October 31. Tremors showing fairly defined phases, with an indicated source 3000 miles distant. North-south component slightly larger than the other. Possibly a Mexican disturbance.

November 10. The time of beginning uncertain and perhaps earlier than indicated, as the first motion develops insensibly from the unbroken line. No tracing on the north-south instrument. Epicenter not known.

December 9. Phases of record undecipherable. The wave motion is preceded by tremulous lines which continue for a long time.

January 1. A fairly strong earthquake, apparently originating about 2000 miles from Albany, perhaps in the Caribbean region. Press dispatches later reported a disturbance in Yucatan on the same day but without information as to the exact time.

January 22. The heaviest quake of the year indicated on the machines, with a maximum amplitude of 30 mm and continuing for more than an hour. It originated in or near Iceland where severe shakings were reported at 7.45 a. m. local time, which is close agreement with the Albany record after allowance for longitude and period of transmission.

January 23. A wavy line, giving doubtful readings.

February 28. Very faint at first, with no decided wave motion for a considerable interval.

March 30. Tracing of a very distant quake.

May 4. The beginning was probably earlier than indicated. This appears to have been the shock which destroyed Cartago, Costa Rica, the only notable earthquake disaster of the year. The record does not give a true measure of the disturbance, which was extremely damaging and violent.

May 13. A characteristic tracing with moderate wave motion. Origin from 4000 to 5000 miles distant.

May 20. This seems to have originated within a relatively short distance, perhaps near Iceland.

June 16. A shock of moderate size, without any clear indications of its source. Slight tremors were reported in certain parts of Spain at about the same time. The north-south component much smaller than the east-west. The different phases are poorly distinguished.

June 20. Two microseisms of which the beginnings are uncertain. The records of June 17 and July 3 are likewise of this class.

July 6. The time indicated for the beginning may really belong to the second preliminaries. North-south component the stronger.

August 4. An earthquake of considerable intensity, showing only a slight movement in east-west direction. It had the appearance of a West Indian disturbance, but may have been submarine. The origin was about 2000 miles away.

August 11. Smaller but otherwise very similar to the shock of August 4.

September 23. Slight oscillations gradually increasing to a maximum and traveling along the meridian.

MINERALOGY

The work of the section of mineralogy has progressed along several lines.

In addition to short papers published during the year the work of investigating the recent mineral occurrences of New York city and vicinity has been inaugurated.

The card catalog of new crystal forms of minerals, mentioned in the last report, has now been published under the title "A List of New Crystal Forms of Minerals."¹

This list, which includes 364 forms, recorded since the publication of Goldschmidt's "Index der Krystallformen der Mineralien," divided among 251 mineral species, is now rendered available to investigators in mineral crystallography.

There have been added to the collections several suites of mineral specimens, of which the most important are:

1 A series representing the more recent Canadian occurrences. This was acquired by exchange with the University of Toronto and contains notably a well-crystallized specimen of barite from Two Islands, Nova Scotia; a large and handsome specimen of kermesite, in well-defined crystalline aggregates on stibnite, from West Gore, Nova Scotia; fine representative specimens of native silver, niccolite, erythrite and smaltite from Cobalt, Ontario; and a small but characteristic specimen of the recently described occurrence of pyromorphite from Moyie, British Columbia.

2 Among the rare mineral specimens from Norway and Sweden, presented to the museum by the Assistant State Geologist,

¹ School of Mines Quarterly, 1910. 31:320.

the following species were not previously represented in the collections:

Native lead from Langban, Sweden; the larger of the two specimens is exceptionally fine, presenting a surface of metallic lead 10 cm by 7 cm in extent.

Melanotekite from Langban, Sweden; a characteristic specimen of this rare mineral.

Pinakiolite from Langban, Sweden; a large characteristic specimen of this rare manganese borate.

Bröggerite from Satersdalen, Norway; a rare crystallized variety of uraninite represented by a well-formed crystal 9 mm in diameter.

Aeschnyrite from Iveland, Norway; a massive specimen of this rare niobate.

3 A representative series of minerals from the pegmatite exposed at Kinkel's quarry, Bedford, Westchester co., was collected during the past summer. This accession contains a fine microcline crystal, 19 x 8 x 7 cm, which shows with clearness twinning according to the Baveno law. Many smaller crystals, some of them developed with almost diagrammatic regularity, form part of this suite. Several specimens of cyrtolite, which has been described from this locality by Luquer,¹ add value to this series, some of them being coated with distinct crystals of the relatively rare mineral autunite. From a specimen of clear rose quartz two perfect spheres, 13 mm in diameter, have been cut, showing the asterism noted in connection with this occurrence by Manchester.

Calcites of New York, by Mr Whitlock, the monograph on this subject which has been mentioned in two preceding reports, has been published as Museum memoir 13. The aim of this work is to discuss the problem of the influence of genetic conditions upon the crystal habit of calcite by means of a close and detailed comparison of the habit of a number of calcite occurrences within the limits of New York State with special reference to the genetic conditions governing the formation of the crystals comprised in these occurrences. The summary of the results of this study indicate a consistent recurrence of closely related crystal forms in three groups of occurrences, in each group of which the governing genetic conditions are similar, notwithstanding the fact that the occurrences of the group are in most instances widely separated geographically.

¹ Luquer, L. McI. Am. Geol. 1904. 33:17.

With a view to rendering a work on so specialized a subject more intelligible to the general scientific reader and to gather together for reference the data available for the general study of the problem, the opening section of the monograph, consisting of 54 pages, is devoted to a theoretical discussion and explanation of terms. This comprises a brief account of the previous crystallographic work done in connection with New York calcite occurrences; a general bibliography of 176 titles covering the crystallographic literature of calcite; and a short discussion of the mathematical relations and formulas fundamental to the study. Under this latter head appears a list of the 313 well-established crystal forms of calcite, including those recorded for the first time in the body of the text, and a list of 115 doubtful or uncertain forms. A gnomonic projection of the above 313 crystal forms constructed on a spherical radius of 7 cm and measuring 100 cm by 90 cm is inclosed in a pocket. This has already proved of considerable service in working out the problems connected with the identification and depiction of calcite crystal forms. In this portion of the work is also included a diagram by the use of which the face outline of any crystal form of calcite may be readily drawn and by this means a model of it constructed in paper or cardboard.

The main body of the work is devoted to a detailed description of the calcite crystals comprised in the twenty occurrences discussed. These occurrences are as follows: Rossie, Antwerp, Sommerville, Sterlingbush, Lyon Mountain, Arnold Hill, Mineville, Chilson Lake, Crown Point, Smith's Basin, Glens Falls, Saratoga, Fayetteville, Union Springs, Howes Cave, South Bethlehem, New Baltimore, Catskill, Hudson and Rondout.

In all about 500 crystals were studied and about one-third of that number were measured. Types, based on crystallographic and genetic differences, are distinguished in the case of most of the occurrences, in one instance (Rondout) as many as nine types being recorded from a single occurrence. Throughout this portion of the work the genetic conditions governing the formation of the various types are discussed and the genetic relations of the types included in each occurrence are studied in some detail.

The crystallographic combinations discussed in the text are shown in 25 plates and include 136 figures.

A synoptic table of distribution of forms shows 100 forms recorded on New York calcite, of which 11 are new to calcite. The 11 new forms do not include those previously recorded by the writer

in his published preliminary work on the Lyon Mountain and Union Springs occurrences.

PALEONTOLOGY

Monograph of the Eurypterida. This work, referred to in previous reports as in preparation, is now on the press. To indicate the general purport and scope of the work the preface to the volume is here appended:

While the senior author of this work was engaged in the preparation of the monograph of the American Devonian Crustacea, which constituted volume 7 of the *Palaontology of New York* (1888), the forms of the Eurypterida there presented for consideration led to the impression that it would be a service to paleontology to restate in detail the structure of this unique group of extinct creatures. The Siluric rocks of New York had long been so profuse in these remains that the material was not wanting for such analysis and the late Professor James Hall, who in 1859 had given the most intimate account of the eurypterids known up to that time, concurred in the belief that the thirty years which had then passed would, with the aid of accumulated data and in the light of the contributions made by other writers, afford new facts worth recording. Not long after this Gerhard Holm published his very remarkable analysis of the structure of *Eurypterus* based on specimens from the Baltic Siluric and on the appearance of this exhaustive memoir it seemed that the anatomy of the group could hardly be supplemented except by the estimation of specific and generic differences, and the study of the habitudes of these animals. Notwithstanding, as early as 1895 I began the assemblage of materials looking specially to a revision of the New York and American eurypterid faunas. The collections of the State Museum were already pretty well supplied with representatives from the well-known localities at Buffalo and in Herkimer county and now these collections have been vastly amplified, first by repeated acquisitions from the Herkimer county localities during the past fifteen years, again by the close study of all outcrops of the *Eurypterus* beds along the line between Herkimer county and Buffalo which has progressed in connection with the field work in areal geology, then by the courtesy of the trustees of the Buffalo Society of Natural Sciences who in 1898, by special vote, placed at my disposal the extraordinary assemblage of specimens from the Buffalo cement quarries which is known, from the name of its principal contributor, as the Lewis J. Bennett collection. Soon thereafter followed the discovery of the *Eurypterus*-bearing black shales at Pittsford, Monroe county, which were brought to light by the work of enlargement of the Erie canal in 1895, the species of which were described by Mr Clifton J. Sarle in our reports, from material now in possession of the State Museum. To this notable addition to our knowledge has been added in years still more recent the new fauna in the dark shales of the Shawan-

gunk grit at Otisville, Orange county, an assemblage of eurypterids remarkable for its profusion of immature growth stages. This fauna, lying far to the east of all previously known occurrences of these creatures, was described in a preliminary way by the writer. Still more recently, indeed since the preparation of this book was believed to be completed, the field investigations of Doctor Ruedemann have brought to light a large and new fauna in the Lower Siluric (Frankfort) shale rather widely disseminated in the lower Mohawk valley; this constitutes the very earliest assemblage of these merostomes in conditions which indicate that they formed a colony of long local duration.

The collections which have thus been brought together from the productive localities mentioned for the preparation of the present treatise have been really great; indeed they represent some thousands of specimens and it is quite within reason to say that no series of the Eurypterida of equal size and variety has ever before been assembled. It is quite as true that no equal area in the world has proved as fruitful in the quantity and diversity of these organisms as the State of New York. Through the courtesy of many correspondents and museums much material from outside of New York has been placed at the demands of this work: the species of the Kokomo waterlimes of Indiana; of the Cambric Strabops of Missouri; the Siluric Megalograptus of Ohio and the Carbonic Hastimima of Brazil and New Brunswick; in all, I believe, an unexampled array of these extinct arachnids.

The work of elaborating these earlier studies and expanding them into this fuller form has very largely depended on the aid of Dr Rudolf Ruedemann who has brought to the work keen analytical powers, a broad grasp of its problems and an enthusiastic assiduity. I fully realize and gladly express my obligation to this assistance and desire that the interested reader accord to my coworker adequate acknowledgment of his efficient part of this work.

The treatise itself seems to carry its own justification; aside from the close analysis of structural details, there are chapters on ontogeny, phylogeny, on life habits and conditions as well as on organization which, though possibly not beyond criticism, are at least informing and constitute an advance of knowledge.

To the following individuals and institutions the authors have been indebted for aid:

The Buffalo Society of Natural Sciences, through its board of trustees and its superintendent, Mr Henry R. Howland

The American Museum of Natural History, through Dr E. O. Hovey and the late Prof. R. P. Whitfield

The United States National Museum, through Drs R. S. Bassler, E. O. Ulrich and David White

The Smithsonian Institution, through Secretary Charles D. Walcott

Columbia University, through Prof. A. W. Grabau and Jesse E. Hyde

Museum of Comparative Zoology, Cambridge, through Dr Samuel Henshaw

The Peter Redpath Museum, McGill University, through Dr Frank D. Adams

Dr E. M. Kindle, Washington

Prof. Stuart Weller, Chicago

Dr Mark E. Reed, Buffalo

Mr Irving P. Bishop, Buffalo

Dr August F. Foerste, Dayton

Mr Fred Braun, Brooklyn

The illustrations in the work are from drawings skilfully rendered by George S. Barkentin; many of them, especially the restorations and stages of immature growth, are based on Doctor Ruedemann's sketches and camera drawings.

The eurypterid colonies of the New York Siluric are very distinctly localized and of them we know two at the bottom of the Salina series or beneath the salt beds and two at the top of the series. These colonies were doubtless partly breeding pools in brackish waters, partly more open basins, restricted in extent by the limitations of favorable physical conditions.

Colony O, or the Otisville basin, lying far eastward of the rest and on the borders of the Appalachian region, is embedded in an almost unlimited repetition of thin black shale between layers of heavy sandstone of the Shawangunk formation (Salina stage). In the construction of railroad improvements the rock wall here was broken down for ballast and while this work was in progress the eurypterid remains were detected by Doctor Ruedemann. From this time until the completion of the construction work referred to Mr H. C. Wardell was almost continuously engaged in acquiring these fossils and when the work was done the rock exposure was left with a vertical face, so that no further product is now available. In this eastern region of New York State the Salina formation is without salt deposits, but the Otisville basin doubtless antedated these deposits in central New York and is assignable to an early part of the Salina stage.

Colony P, or the Pittsford pool, is embedded in a black shale formation which has never been exposed in any natural outcrops. As we have observed, the rock was first brought to light by excavations made in the deepening of the Erie canal in 1895 and the outcrops were soon after covered by the riprap construction of the canal lining and so remain. Extensive collections of material were made by Mr Clifton J. Sarle; these were subsequently increased by the work of Messrs D. D. Luther, H. C. Wardell and Fred Braun. The opportunity of further acquisitions from this fauna rests with the future and depends on possible new excavations in the progress of public improvements.

Colony H, or the Herkimer pool, has been long exploited. It lies above the horizon of the salt and its localities are in the vicinity of Jerusalem Hill, Clayville, Sauquoit and Waterville. The most

productive parts of the region have been the Wheelock and Schooley farms near Jerusalem Hill, though here as elsewhere actual outcrops of the waterlime are few. Experience has shown that the exploitation of the fresh rock does not afford eurypterids in satisfactory preservation, because of its blue-gray character. Exposure not only reduces this to a light gray but aids the fissility of the rock and the broad, flat surfaces of the fossils also help to induce cleavage planes in the matrix. Exposure of a few years to the weather aids but little. The experiment was made of taking from the outcrop a good many cords of fresh rock which were left exposed for a period of five years, but the result in the particulars referred to was wholly unsatisfactory. Therefore the supply of these fossils has come from weathered slabs distributed over this region. Miles of stone fences have been inspected and many rods of them taken down and rebuilt. Some of the most productive material has been found in the foundations and cellar walls of buildings and in one instance the foundation wall of a large barn has been removed without disturbing the building, the abstracted rock being replaced with concrete as the work proceeded. Many hands have helped in the acquisition of this material: Messrs D. D. Luther, R. Ruedemann, C. A. Hartnagel, Jacob Van Deloo, H. C. Wardell, Fred Braun and the writer, and while it may be difficult at present greatly to enlarge these extensive collections, still they are only an index of the profusion of these forms of life in this pool.

Colony B, or the Buffalo pool, appears to have been quite closely confined to the quarry beds of the Buffalo Cement Company in the northern part of the city of Buffalo. It is from these quarries that has come the majority of the specimens now widespread through the museums of the world. Formerly such specimens were available to any collector, but a few years ago the president of the company determined to place all specimens uncovered in the progress of quarry work in the possession of the Buffalo Society of Natural Sciences and by virtue of this laudable act that society possesses in the "Bennett Collection" a very remarkable array of these remains, which are specially noteworthy for the prevailing large size attained by the individuals. At the present time few Eurypterida are obtained from this historic locality and there is reason to believe that the boundaries of the pool have been approached, though remains of these creatures are found scattered at this geological horizon as far west as Bertie, in Ontario, the locality from which this waterlime formation takes its name. Like the Herkimer pool, that at Buffalo lies in the Bertie waterlime above the salt.

Colony S, or the Schenectady basin. This recent discovery (1910) of eurypterids in the Frankfort shale (Lower Siluric) is comparable to their occurrence at Otisville. These remains, usually in fragmentary condition, abound most freely in fine-grained black shale intercalated between thick calcareous sandstone beds locally known as "Schenectady bluestone," but they also occur in the sandy

passage beds between the two. These sandy shales are full of organic remains, partly of the supposed seaweed *Sphenothallus latifolium* Hall and partly of what appear to be large undefined patches of eurypterid integument. In the black shales the eurypterid remains are rarer but their surface sculpture is excellently retained, and here their organic associates are *Climacograptus typicalis* and *Triarthrus becki*. As a result of imperfect retention of these eurypterids in the rocks where they most abound and their sparseness in the shales which have best preserved them, we are still left in ignorance of the full composition of this assemblage, but it is safe to say genera, species and individuals were abundant at this early period and the evolution of distinctive characters which we have heretofore recognized only in a later period had progressed to so sharp a differentiation, that we are compelled to carry back farther in history, some of the commoner generic designations. These remains in the Frankfort shale are distributed through fully 1500 feet of strata off a northeast-southwest coast line in an area of maximum deposition and it is difficult to conceive that the physical conditions of the habitat of these merostomes were those of an inshore pool; they were rather those of a purely marine basin where sedimentation went on rapidly in an appalachian depression. Hence among our assemblages of these creatures this occurrence is without parallel in respect to long endurance, while in the nature of the habitat it is comparable to that at Otisville.

All other occurrences of Siluric eurypterids in New York have been desultory and indicate no intercommunication between the pools or colonies mentioned.

Monograph of the Devonian Crinoidea. This work is progressing and the addition of new material has somewhat broadened its scope and usefulness. Its advancement is necessarily slow because of the inability of its author, Mr Kirk, to give his consecutive attention to it, but the field is being gradually covered fully and the work should result in a useful addition to the paleontology of New York.

Collections. Considerable collections of fossils have been made in the field, particularly from the Clinton formation of Oneida county, for the purpose of determining the rational position of this formation and fauna in the rock series. Excavations in the Agoniatite limestone of the Marcellus division have resulted in procuring a ton or so of material illustrating the large goniatites and other cephalopods of that horizon, of which the museum collections stood in need. This work has been done by Mr Hartnagel. Doctor Ruedemann has carried on investigations into the nature and relations of the shale formations of the lower Mohawk and upper Hudson valleys by extensive collecting throughout this region.

III

REPORT OF THE STATE BOTANIST

The following is a summary statement of the progress and results of the work of the State Botanist for the past year.

Specimens of plants for the herbarium have been collected in the eastern, northern and western part of the State. They are from the counties of Albany, Chemung, Columbia, Essex, Greene, Livingston, Rensselaer, Saratoga, St Lawrence, Steuben, Ulster and Warren. The number of species of which specimens have been added to the herbarium, including those collected and those contributed by correspondents, is 269. Of these, 79 species are new to the herbarium and 23 are considered new to science. The new species are all fungi.

One hundred and seventy-six persons have contributed specimens. This number also includes those who sent specimens for identification only, if the specimens were collected in this State and were desirable additions to the herbarium. There were made 2419 identifications of specimens sent by correspondents or brought to the office by inquirers. Both the number of persons for whom identifications were made and the number of identifications are decidedly larger than in any previous year. For 1909 the corresponding numbers are 152 and 1717. This indicates a gratifying increase in the general desire for botanical knowledge.

Specimens of five species of *Crataegus* have been added to the very large number already represented in the herbarium. Four of these are new to our flora.

Specimens of five species of mushrooms have been collected, tried for their edible qualities, and approved. These make the number of our New York edible species and varieties now known 205. Life-size colored figures and full plain descriptions of the five added species have been prepared. One species has been found to be remarkable for its sudorific qualities. If eaten freely it causes profuse perspiration, but no other inconvenience. Its flavor, texture and digestibility are faultless, but it should be considered medicinal rather than edible.

In pursuance of a previous plan, a monograph of the New York species of *Hypholoma* has been prepared. The genus includes several sections which, while agreeing in the common character of having a marginal veil, are in no other respects quite unlike each other. This, coupled with the fact that in any one group closely

related species are found, makes a revision and collation of the New York species of the genus especially desirable.

Having been informed that the raspberry patches of the fruit growers in the vicinity of Marlboro, Ulster county, were suffering from a disease, a visit was made to that place in July and some of the diseased plants examined. They were found to be principally affected by a parasitic fungus, *Sphaerella rubina* Pk. The fruiting canes put forth their leaves and blossoms as usual and commence to develop their fruit, but before it ripens it withers and dries on the branches. The dryness of the season doubtless aided the destructive tendencies of the fungus and the loss was severe. The diseased canes bore patches of the fungus but it had already distributed its spores, which, according to previous observations made on the type specimens, mature early in the season, even in April and May. In consequence, the young canes showed brown or blackish patches on the lower part, in some cases near the ground, thereby showing that they had already been infected and in their turn would probably bear a crop of spores next spring. It would seem to be possible to check this disease by spraying the young shoots with fungicides, but the spraying should evidently begin as soon as the young shoots are three or four inches high, and be repeated once a week till the blossoms begin to open.

While at Marlboro, the attention of the Botanist was called to a diseased chestnut tree. It was a young tree with sickly looking foliage and a few dead branches. It was suffering from the chestnut bark disease about which much that is sensational and needlessly alarming and pessimistic has recently been published. This is the only instance recorded of its occurrence in Ulster county and, with one exception, the most northern station for it in this State. It has been reported from as far north and west as Cooperstown but no specimens from that locality have been examined and it probably does not yet occur west of the Hudson river valley, unless possibly in a few widely separated and limited, isolated stations. The most northern station for this disease is Vischer's Ferry, Saratoga county. It is an apparently outlying station, no intervening one between it and Marlboro being known.

In 1899 a census of the species of plants found in Bonaparte swamp, Lewis county, was taken and a list of the names of the species was published in the report for that year. The number of flowering plants and ferns found there is 128. The swamps and marshes of the State are a part of its natural resources. They are

the result of a long, slow process by which shallow lakes are transformed into plant-producing areas, or, in other words, in which water surface is changed to land surface. In this process plants play an important and very large part. In the beginning, aquatic plants and aquatic and sphagnous mosses occupy the more shallow parts of the lake. By the annual growth and decay of these a mass of sedimentary material, which is largely vegetable in its composition, accumulates. This gradually spreads till in many cases it occupies nearly or quite all of the lake surface. In due time it becomes sufficiently dense and firm to sustain amphibious and marsh-loving plants. These gradually take possession and carry on the work till the consistency of the surface is sufficient to give support to marsh grasses and sedges, which give us what is locally known as "beaver meadows."

In some cases, instead of a grassy marsh there is formed a shrubby marsh in which small shrubs have taken possession instead of or in connection with the grasses and sedges. By their intermingling roots and the annual falling of leaves the surface becomes denser. The next stage is ushered in when swamp-loving trees can maintain an existence. These gradually become numerous enough to overpower and suppress much of the herbaceous vegetation and many of the smaller shrubs, and the wooded swamp results. The borders of a marsh may be and often are simply a wooded swamp which itself is only an older part of the marsh. The grassy marsh appears to be less inviting to the advent of trees than the sphagnous and bushy marshes and, prairielike, it often remains open an indefinite time. Cleared swamps and open grassy marshes may, by proper drainage and treatment, be turned into productive land. The products of the marshes are sometimes utilized. The fruit of the various species of *Vaccinium* is gathered for food. The grasses and sedges of the "beaver meadows" are sometimes cut for hay, but this is rarely done except in cases of scarcity or very high prices of hay of better quality. The partly decayed remains of the vegetation of the marshes constitute peat. The less fibrous peat is used for heating purposes, fertilizers, and as an absorbent or bedding material in stables. The more fibrous kinds which come especially from shrubby or grassy marshes are used for purposes demanding a more fibrous material. That we might have a more definite knowledge of the species of plants most active in the transformation of our marshes into a more useful condition, a list of the plants at present found growing in Cranberry marsh, Sand

lake, Rensselaer county, and in Averyville marsh, North Elba, Essex county, has been made. Two visits were made to the Cranberry marsh, one in July and one in September. A few plants were found on the second visit that were not seen on the first, presumably because they had not yet developed sufficiently to attract attention. The whole number of species found in this marsh is 72.

One visit was made to Averyville marsh. It was in September, and though the marsh covers a larger area than the Cranberry marsh, only 58 species were found there. This is probably due in part, at least, to the lateness of the visit. The number of species common to the two marshes is 33. More than half the number of species found in Averyville marsh occur also in Cranberry marsh. Of the species common to the two marshes, 15, or nearly half, are trees and shrubs. If we compare the list of species in Bonaparte swamp with those of the two marshes we find only 19 species common to the three localities. The flora of the wooded swamp is seen to be quite unlike that of the open marsh, as might be expected.

PLANTS ADDED TO THE HERBARIUM

New to the herbarium

<i>Amanita bisporigera</i> <i>Atk.</i>	<i>Cycloloma atriplicifolium</i> (<i>Spreng.</i>)
<i>A. floccocephala</i> <i>Atk.</i>	<i>Cytospora microspora</i> (<i>Cd.</i>) <i>Rabenh.</i>
<i>A. velatipes</i> <i>Atk.</i>	<i>Diplodia linderæ</i> <i>E. & E.</i>
<i>Ascochyta menyanthis</i> <i>Oud.</i>	<i>Eccilia mordax</i> <i>Atk.</i>
<i>Aulographum ledi</i> <i>Pk.</i>	<i>Eurotium subgriseum</i> <i>Pk.</i>
<i>Biatora coarctata</i> (<i>Sm.</i>) <i>Nyl.</i>	<i>Gloeosporium caryæ</i> <i>E. & D.</i>
<i>Calvatia craniiformis</i> (<i>Schw.</i>)	<i>G. divergens</i> <i>Pk.</i>
<i>Camelina sativa</i> (<i>L.</i>) <i>Crantz.</i>	<i>Grindelia squarrosa</i> (<i>Pursh.</i>) <i>Dunal</i>
<i>Cercospora phlogina</i> <i>Pk.</i>	<i>Helianthus petiolaris</i> <i>Nutt.</i>
<i>Cladosporium paeoniae</i> <i>Pass.</i>	<i>Heterothecium pezizoideum</i> (<i>Ach.</i>)
<i>Climacium kindbergii</i> (<i>R. & C.</i>)	<i>Hygrophorus caprinus</i> (<i>Scop.</i>) <i>Fr.</i>
<i>Clitocybe biformis</i> <i>Pk.</i>	<i>Hypericum prolificum</i> <i>L.</i>
<i>C. maxima</i> <i>G. & M.</i>	<i>Hypochnus tristis</i> <i>Karst.</i>
<i>Cortinarius croceofolius</i> <i>Pk.</i>	<i>Hypoloma delineatum</i> <i>Pk.</i>
<i>C. glaucopus</i> (<i>Schaeff.</i>)	<i>Inocybe rimosoides</i> <i>Pk.</i>
<i>C. napus</i> <i>Fr.</i>	<i>Lactarius boughtoni</i> <i>Pk.</i>
<i>C. triumphans</i> <i>Fr.</i>	<i>Lentinus piceinus</i> <i>Pk.</i>
<i>Crataegus aristata</i> <i>S.</i>	<i>Lychnis coronaria</i> (<i>L.</i>) <i>Desr.</i>
<i>C. brainerdi</i> <i>S.</i>	<i>Machaeranthera pulverulenta</i> (<i>Nutt.</i>)
<i>C. calvini</i> <i>S.</i>	<i>Macrosporium heteronemum</i> (<i>Desm.</i>)
<i>C. longipedunculata</i> <i>S.</i>	<i>Marasmius contrarius</i> <i>Pk.</i>
<i>C. nemorosa</i> <i>S.</i>	<i>Myxosporium carpini</i> <i>Pk.</i>
<i>Crepis setosa</i> <i>Hall. f.</i>	<i>Naemospora croceola</i> <i>Sacc.</i>
<i>Cryptosporium macrosperrum</i> <i>Pk.</i>	<i>Naucoria sororia</i> <i>Pk.</i>

Oidium asteris-punicea <i>Pk.</i>	Rhabdospora physostegiae <i>Pk.</i>
Oxybaphus floribundus <i>Chois.</i>	Scirpus occidentalis (<i>Wats.</i>) <i>Chase</i>
Pertusaria leioplaca (<i>Ach.</i>)	Sideranthus gracilis (<i>Nutt.</i>) <i>Rydb.</i>
Pholiota terrigena <i>Fr.</i>	Sphaeropsis smilacis latispora <i>Pk.</i>
Phoma piceina <i>Pk.</i>	Sporotrichum grisellum <i>Sacc.</i>
<i>P.</i> simillima <i>Pk.</i>	Theloschistes flavicans <i>Wallr.</i>
<i>P.</i> stictica <i>B. & Br.</i>	Thlaspi perfoliatum <i>L.</i>
Phyllosticta betae <i>Oud.</i>	Trichothecium subgriseum <i>Pk.</i>
<i>P.</i> subtilis <i>Pk.</i>	Triosteum perfoliatum <i>L.</i>
Physcia hispida (<i>Schreb.</i>)	Usnea trichodea <i>Ach.</i>
Picris hieracioides <i>L.</i>	Vermicularia beneficiens <i>Pk.</i>
Pilocratera abnormis <i>Pk.</i>	<i>V.</i> pomicola <i>Pk.</i>
Placodium ferrug. discolor <i>Willey</i>	Verticillium agaricinum (<i>Lk.</i>) <i>Cd.</i>
Plasmodiophora elaeagni <i>Schroet.</i>	Viburnum venosum <i>Britton</i>
Pleurotus approximans <i>Pk.</i>	Vicia villosa <i>Roth</i>
Ramalina rigida (<i>Pers.</i>) <i>Tuck.</i>	

IV

REPORT OF THE STATE ENTOMOLOGIST

The State Entomologist reports that the past season has been remarkably quiet so far as unusual outbreaks of injurious insects are concerned. The Entomologist was exceptionally fortunate in discovering a colony of pedogenetic larvae, presumably those of *Miastor americana*. These extremely peculiar forms were previously unknown in this country and have been studied by only a few Europeans.

Fruit tree pests. The experimental work with the *codling moth* was continued during the present season under more diverse conditions and data secured which will be of great value in the practical control of this species. The experiments were conducted in the orchards of W. H. Hart, Poughkeepsie; C. R. Shons, Washingtonville, and William Hotaling, Kinderhook. Great care was taken to secure an ample number of trees likely to produce a nearly uniform amount of fruit. As last year each plot, except in the case of Mr Hotaling's orchard, consisted of 42 trees, the fruit from the central six alone being counted. Comparisons were made to ascertain the relative efficacy of one spray given just after the blossoms dropped, with this treatment supplemented by a second application about three weeks later. The unusual abundance of the codling moth during the past season renders the data secured of exceptional value because they show the possibilities under very adverse conditions.

The *San José scale* is still very destructive, especially to peach

trees, though our progressive orchardists have comparatively little difficulty in controlling it. A lime-sulfur wash, particularly that known as the concentrated wash, either homemade or commercial, has proved very satisfactory, as a rule, in checking this pest. In the Hudson valley there was complaint of injury by the *cherry maggot* and an investigation of the pest and methods of controlling it was inaugurated. The *cherry and pear slug* was exceptionally abundant in this region and also in the western part of the State. The *pear psylla* was somewhat abundant in the lower Hudson valley and reports of serious injuries were received from certain sections in the western part of the State.

The work of a new apple pest which may be known as the *lined red bug* (*Lygidea mendax* Reut.) was observed in the Hudson valley. This insect occurs in early spring, lives upon the more tender terminal leaves and, under favorable conditions, may inflict considerable injury.

Shade tree pests. The injurious work of various species has been brought to our notice. The more important of the shade tree pests is the *elm leaf beetle*, a well-known form which has been exceedingly abundant on Long island, throughout the Hudson valley and in certain cities in the western part of the State. The *sugar maple borer* has been unusually numerous on the trees of Fulton, Oswego county, destroying or practically ruining a number of magnificent trees. The *cottony maple scale* has been somewhat abundant in the lower Hudson valley, while the injurious work of the *false maple scale* was observed in several localities in the vicinity of New York city.

Forest insects. The *snow-white linden moth*, a pest which has been very destructive in the Catskills for the past three years, was abundant in limited localities last season and its flight in small numbers was observed in various places. A series of outbreaks by another leaf feeder was reported from several localities. They were due to the operations of a green, white-striped caterpillar (*Xylina antennata*) frequently designated as the *green fruit worm*. The destructive work of the *hickory bark beetle*, noted in a preceding report, has been continued. An unusual outbreak was that of *Abbott's sawfly*, a false caterpillar which stripped or nearly defoliated many white pines in the foothills of the Adirondacks. The *spruce gall aphid* has continued to be abundant and injurious on Norway spruce, in particular. It is interesting to record the discovery of another species of gall aphid, new to the

State, occurring upon the Colorado blue spruce. The above noted insects have been the subject of correspondence and, in some instances, of field investigations during the past season.

Gipsy and brown tail moths. Much interest was aroused early in 1909 by the finding of thousands of winter nests of the brown tail moth on many shipments of French seedlings. A number of such nests occurred on shipments received in 1910, though the pests were not so abundant as during the preceding year. The careful inspection of the stock appears to have prevented this insect from becoming established in the State. There is much more danger of this moth being brought into New York State on shipments of full-grown nursery stock originating in infested American territory than there is of its being introduced with imported seedlings. It has been found necessary to give considerable time to the determination of remains of caterpillars, cocoons and egg masses in order to be certain that none of these fragments on nursery stock indicated the presence of either the gipsy or brown tail moth.

A personal investigation of conditions in eastern Massachusetts shows that no pains are being spared to prevent the dissemination of either the gipsy or the brown tail moth. Particular attention has been given to keeping the property abutting on the principal highways free from the pests so as to eliminate in large measure the danger of their being carried by vehicles of any kind. There has been, however, some extension of the territory occupied by these two pests. The gradual spread of these insects appears to be inevitable, though the utmost care is taken in the treatment of the outlying colonies. It is gratifying to state that the serious infestation recently discovered at Wallingford, Conn., has been handled in such a satisfactory manner that only a very few specimens rewarded a week's careful search by a gang of fifteen men. An examination of the work with parasites showed that no stone was being left unturned in an effort to find, rear and liberate a large number of efficient enemies of these pests. The Entomologist would emphasize once more the grave danger of bringing either one or both of these pests into the State on nursery stock originating in the infested area, and would call attention to the great desirability of promptly exterminating any isolated colonies which might be found in the near future.

House fly. The popular interest in the control of this pest has continued and bids fair to result in important and far-reaching sanitary changes. The demand for information exhausted the

edition of Museum Bulletin 129 on the *Control of Household Insects* and necessitated its republication in an extended and revised form as Museum Bulletin 136 entitled *The Control of Flies and Other Household Insects*. The Entomologist has been called upon to give a number of popular lectures upon this insect and has made personal examinations of conditions in several localities, giving special attention to situations favorable for the production of flies in cities and villages.

Gall midges. Studies of this extensive and interesting group have been continued and the results are now in manuscript. This publication will describe fully some 800 species, 441 having been reared. The tabulation of plant galls, made with the assistance of Miss Hartman, shows that we know some 538 species representing 44 genera and living at the expense of some 177 plant genera referable to 66 plant families. In addition to the above, there are some 5 species reared from unknown plants and 11 species belonging to 3 genera known to be zoophagous.

A number of new species have been reared during the year. Miss Cora H. Clarke of Boston, Mass., has continued to collect and forward to us excellent series of galls from which we have been able to rear several previously unknown species. The care of this material has devolved largely upon D. B. Young and Miss Hartman. The latter has also made a large number of microscopic mounts of these fragile forms.

Miscellaneous. The Entomologist spent nearly six weeks in Europe, giving special attention to museum methods, shade and forest tree insects and the gall midges. Collections were studied in the following institutions: British Museum of Natural History, London; the Universities of Oxford and Cambridge; the Tropical School of Medicine, Liverpool; the zoological gardens at Antwerp; the Royal Museum of Natural History at Brussels; the botanical gardens of Ghent; Museum of Natural History and the entomological station at Paris; the University at Zurich; the exceptionally valuable collection of forest insects in the Forestry School at Munich; the natural history collections in the Senckenberg Museum at Frankfurt; the Winnertz collections in the University of Bonn; the Museum of Natural History, Berlin, and the Museum of Natural History at Hamburg. In addition, the Entomologist spent several days with Prof. J. J. Kieffer of Bitsch, Germany, studying

his exceptionally valuable collection of Cecidomyiidae, and with Prof. E. H. Rübсаamen at Remagen, Germany, a day devoted largely to examining his numerous excellent drawings and a discussion of the classification of this group. A portion of a day was spent with Oberförster H. Strohmeyer of Münster, Germany, studying his excellent collection of Scolytidae, while another day was passed with Oberförster Karl Philip at Sulzberg obtaining first-hand information of forestry methods as practised in Germany.

Publications. Numerous brief, popular accounts dealing with injurious insects have been prepared by the Entomologist for the agricultural and local press, besides a few more technical papers for scientific publications. A revision of Museum Bulletin 129, as noted above, was issued during the year, while the report for 1909 appeared last July. A tabulation of the midge galls known to occur upon several plants was published in August under the title of *Gall Midges of Aster, Carya, Quercus and Salix*.

Collections. A valuable addition to the collections was secured through the generosity of Prof. J. J. Kieffer, of Bitsch, Germany, who kindly donated to the museum a number of his generic types of European gall midges. These have been carefully mounted and are accessible to students of the group. A fine series of Italian midge galls was secured by exchange with Dr Mario Bezzi. These were carefully arranged and labeled by Miss Hartman. Miss Cora H. Clarke, as already noted, has contributed some valuable biological material, mostly insect galls.

The arrangement and classification of the collection has been forwarded as rapidly as possible, though with the limited office staff it is practically impossible to keep the collections properly classified, while the securing of desirable additional material must of necessity proceed slowly. The restrictions due to a small staff will become more apparent with the occupancy of quarters in the new building, accompanied by the obligation of maintaining a larger exhibit. The school teachers of Albany, Troy and presumably other near-by localities are making extensive use of our exhibit collections in connection with the regular school work. It is the aim of the Department to have a representative collection of the species occurring in the State, though the assembling of such means the work of years.

The nearly completed monograph on the gall midges shows that

the State collections in this family will far exceed anything that can be assembled elsewhere for some years to come. It will always be valuable because of its very large series of generic types or cotypes. Mr Young has identified and arranged the Conopidae, besides doing much miscellaneous work in classifying insects collected during the year and identifying species sent in for name. A number of Hemiptera have been very kindly determined by a well-known authority in this group, Mr E. P. Van Duzee of Buffalo. Miss Hartman has also assisted in the arrangement of the collection and has reared and spread a number of specimens.

The value of the exhibit collections will be greatly enhanced when the series of plant groups designed for the exhibition of insects in their natural environment in the new Education Building has been completed. The wax work for four of these groups has been delivered and it is planned to complete the remainder next year. Several excellent models representing injurious insects are now on exhibition and more should be secured, preferably made to order, since only a few can be purchased in the market, while no one has attempted to prepare models of many forms which could be exhibited in this manner to very great advantage.

Nursery inspection. There has been close cooperation with this phase of the work conducted by the State Department of Agriculture. Numerous specimens of both native and foreign insects have been submitted to this office for name, and the Entomologist has been frequently consulted in regard to various problems. This work, while consuming much time and often necessitating identifications of minute forms, like scale insects or the recognition of species by fragments or the comparatively unknown early stages, is very important, since the treatment of large shipments must depend in great measure upon our findings.

Office matters. The general work of the office has progressed in a satisfactory manner, the Assistant State Entomologist being in charge of the office and responsible for the correspondence and other matters during the absence of the Entomologist in Europe and while away on vacation. Miss Hartman, in addition to matters noted above, has rendered material assistance in bibliographic work and in translating from German, French and Italian works. Numerous specimens have been received during the year for identification and many inquiries made concerning injurious forms.

V

REPORT ON THE ZOOLOGY SECTION

During the year the Zoologist, Frank H. Ward, and the Taxidermist, Alfred J. Klein, both tendered their resignations and left the service of the Department. Up to his departure, Mr Ward devoted most of his time to the arrangement and labeling of the shell collections and to plans for the exhibits, and especially for the cases, for the hall of zoology in the Education Building. As a result of his work, Mr Ward left a plan covering the different types of cases that will be required, the dimensions and number necessary for each type, and their arrangement in the hall. In its main features this plan seems entirely satisfactory, providing the necessary space and a logical arrangement of the material, as well as allowing for growth along the lines on which it is proposed to develop the museum.

The necessity of this and other work looking toward the coming change of quarters, as well as the lack of space in Geological Hall, not only for the exhibition, but also for the storage of more specimens, prevented the staff from undertaking any field work, so that the accessions along some lines are less than usual, yet the total number of specimens added was raised to a figure far beyond that reached for many years by the purchase of the Ingalls collection of shells, comprising, according to an estimate by Mr Ward, a total of about 24,000 specimens from all parts of the world. While its purchase must be regarded as a departure from the plan of confining the collections of this museum to the natural history of New York State, yet the rank long held by this institution among collections of Mollusca is so high as to deserve to be maintained, in so far at least as can be done without materially interfering with the development of the collections along the lines which have been determined on as most important.

The cases for the fish and mink groups mentioned in the last report were received and set up in Geological Hall, but further additions to the exhibits in this building are out of the question for lack of space, and this same difficulty has seriously delayed the preparation of the large mammal groups which are contemplated, or for which specimens have already been acquired. A group of four porcupines with accessories was completed by Mr Klein, who held the position of Taxidermist until September 1, 1910, but it awaits not only a case, but room for setting it up.

A number of casts of native reptiles and amphibians was also purchased, as these casts show the natural color and appearance of the animals better than either stuffed or alcoholic specimens. A consistent effort has been made to get together the materials for more bird and mammal groups, even though all attempts to set them up must be deferred until more room is available. With this end in view the Zoologist made a trip to Silver Bay to examine the collections of Mr Silas H. Paine who had an extensive private collection that was being broken up and sold. Many of the best specimens had been bought by others before this museum was notified that they were for sale, but several good bird groups and much material useful in setting up other groups remained and negotiations for its purchase were in progress at the end of the fiscal year.

Birds of New York. The first volume of this work covering the water and game birds has been issued, under authorship of Prof. E. Howard Eaton, with forty-two plates in color by Louis Agassiz Fuertes. The public demand for this publication has been very large and it has, on this account and in view of the limited edition, been necessary to restrict the distribution very largely to sales. A larger edition is required in order to meet the reasonable requirements of the citizens and it is believed this will be provided. The second volume of the work, which will embrace the land birds, is practically completed and its publication within a year is confidently hoped for.

VI

REPORT ON THE ARCHEOLOGY SECTION

The work of this section of the museum embraces a number of coordinate sciences which cover nearly all divisions of anthropology. Among the special branches to which attention is devoted may be mentioned ethnology, folklore, archeology and human osteology. Most of these subjects require research in the field. Other special work is the securing of Indian models for casts, the supervision of the work of the sculptors and artists and directing the collection and production of the various accessories necessary for the series of ethnological groups. This is referred to in greater detail hereinafter.

It will be noted that the term archeology as applied to this section of the museum's activity is descriptive of only one of the important branches of its researches and that the term anthropology conveys a more accurate impression of the scope of work pursued.

The field of research. The special line of investigation to which the attention of the Archeologist is directed is that of studying the culture of the aborigines of New York, both that of the past and of the present. This is done in order to bring to light data for correlation. Many of the fundamental facts of anthropology have been gleaned from the study of the American Indians. In our State there lived, and now live, representatives of a very important and highly developed Indian stock. Much has been written of the New York aborigines, but much of their culture remains unrecorded and various facts they present are very significant.

Our work is limited primarily by the lines of the State. Within these bounds we make systematic surveys and excavations of the various sites of aboriginal occupation, and instal the various artifacts and other materials bearing on the culture-history of our Indians in the archeological collections of the State Museum. The State is our field and wherever suitable sites can be found these are examined or excavated. This, with the collection of the relics and specimens of Indian art, constitutes the work in archeology.

Various tribes and stocks have inhabited this area during remote times and even now remnants of some exist. Each tribe or stock, except perhaps the earliest, has left traces by which it may be differentiated from the rest. To sift out the problem of the different successive or contemporary occupations, to discover lines and times of migrations and to determine the cultural facts, form a field of research for constant activity.

The Indians that yet remain in this State are the various tribes or nations of the Iroquois, viz: the St Regis Mohawk in Franklin and St Lawrence counties; the Oneida in Madison county; the Onondaga in Onondaga county; the Seneca in Cattaraugus, Erie and Chautauqua counties; the Tuscarora in Niagara county; and the Cayuga who live mostly with the Cattaraugus Seneca. A few Abenaki, survivors of the Canadian Algonquin, live in the Adirondacks in the vicinity of Lake George, while others are scattered throughout the State.

Few tribes of North American Indians have occupied so prominent a place in history and literature as the Iroquois. Their conquests, their government, their endurance as a people, and their keen intellect, wonderful sagacity and political capacity as individuals have excited the admiration of even their enemies. Thousands of pages have been written on the Iroquois and yet so full of interest is their history that as a subject for the historian, the romancer or the anthropologist, they furnish a never failing topic for discussion.

An examination of the pages of the works on the Iroquois reveals that but little has been added to the sum total of knowledge about them since the time of Colden and later the time of Morgan. Many writers, it is true, such as Schoolcraft, Hale, Clark, Boyle and Beauchamp, have contributed much of importance, but the fact remains that no thorough ethnological study has ever been made. A vast reservoir of data remains untapped, and in stating this the truth is not overdrawn. So much about the Iroquois remains to be learned that all that has been recorded seems but a pittance. To grasp this work and rescue from oblivion the knowledge which is now within our grasp is the work of a lifetime, but within a lifetime a great part of it will be beyond the reach of human effort. The minds that know and hold the old-time lore will have passed into the great silence. In this state of conditions the ephemeral things of museum routine ought not to be permitted to interfere with the opportunity that lies before us.

Among the ethnological subjects which have been matters of study may be mentioned Iroquois mythology, folk cults, dreams and dream influence, gesture and emotional language, names and the doctrine of names, costumes and personal ornament, sign language, symbols, decorative art, periodic ceremonies, wampum records, the code of Dekanowideh and the code of Handsome Lake. Notes on many other subjects are awaiting elaboration.

Information on many of these subjects is totally lacking and is not to be had outside of our notes, which are as yet, in most cases, only outlines.

Several large collections of archeological material have been offered us, but without funds it is not possible to acquire them. Most of these collections are invaluable and can never be duplicated. In many instances they represent the greater part of the relics collected in a given region and are the result of years of investigation.

There is no legitimate reason why funds should not be appropriated for the purchase of this material, which by every reason should become the property of the State. The interest of other institutions both here and abroad in these collections has led to the purchase of some and their removal beyond our control. The State of New York can hardly afford to permit the loss of this vast historical and archeological wealth, and yet mistaken policy has permitted it in the past.

No attempt has been made to rearrange the archeological collections, since there is no means of displaying any collections, however

well arranged. It is likewise difficult to remove the numerous objects that crowd upon one another because our storage room is limited and the short time when proper facilities will be provided would make the work a waste of important time.

During the year the Archeologist examined several of the old collections that had long been in storage and endeavored to check the specimens found, against the catalogs. Many specimens were missing, having disappeared through the years. Several boxes taken from storage in the malt house contained only dust and shreds of cloth, the result of destruction by mice. Even some of the more recent specimens had been almost destroyed by moths. This destruction of important objects is largely the result of improper and limited exhibition space and the previous lack of permanent curators.

Public interest. The interest of the public in the work of this section is steadily increasing as is attested by the call for its publications, the visits of interested collectors and the hundreds of letters from persons desiring information about anthropological subjects. Visitors and letters come not only from our own State, but from many parts of this continent and from Europe. The plans for the large ethnological exhibit have awakened the interest of museum officials from many institutions who have either written or called in person.

The range of inquiries directed to us is wide and covers the entire field of anthropology and Indian history.

It is the aim of the archeological section to arrange its exhibits in the new Education Building so as to especially appeal to the public interested in Indian relics and lore. In preparing these exhibits the fact is borne in mind that the State Museum is the people's museum and that its function as a division of the Education Department is to educate and not to confuse those who view its collections. Such a plan will in no wise impair the scientific value, but rather increase it and at the same time add much to popular interest and education.

ETHNOLOGY

The work of this division of our researches has been especially productive of results both in the acquisition of important specimens of Iroquois and Algonquin handiwork and in the important notes recorded.

The Archeologist during his various field trips for Indian models has used his spare moments on the Iroquois reservations in New

Plate 1



Symbolic and ornamental decorations embroidered on buckskin with moose hair and porcupine quills

York and Ontario in seeking information regarding ceremonial rites, folk cults, myths etc., and in collecting such ethnological material as could be acquired by purchase. In this latter matter, although much of great historic and scientific value was found, it was impossible to acquire everything because of limited funds at hand.

During the year 160 ethnological specimens have been acquired.

Fig. 1

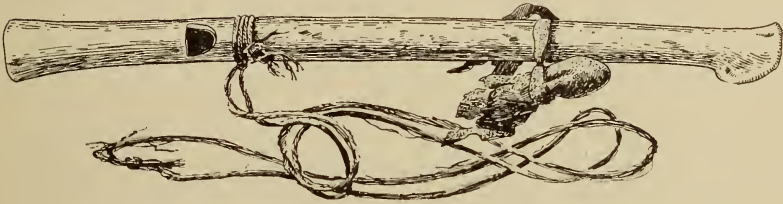
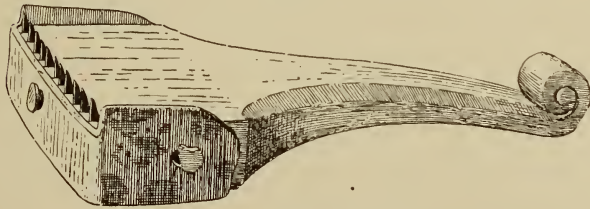


Fig. 2



Fig. 3



Ethnological specimens

- Fig. 1 Little water flute made of a turkey bone
 Fig. 2 Crooked knife with an antler handle
 Fig. 3 Splint gauge

All about one-half natural size

Special subjects of inquiry and study during the year have been the art and symbolism of the New York aborigines, costumes and personal adornment, and Iroquois uses of maize and other food plants. The notes on the last mentioned subject, the result of some ten years research, were revised, annotated and presented for publication as a bulletin.

Much attention has been given to the study of the decorative art and symbolism of the New York Indians, which resulted in revising and enlarging a manuscript monograph on the subject and holding it as the nucleus for further study. With the Iroquois, the

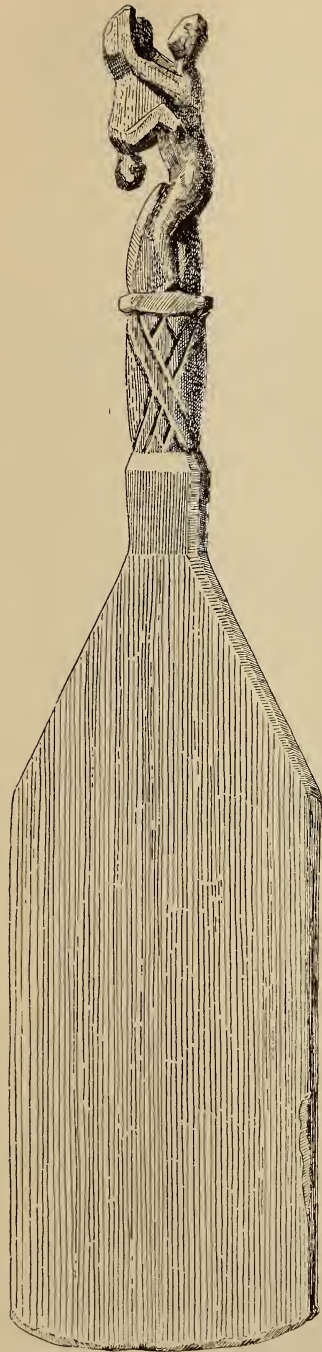


Fig. 4 Ceremonial paddle. Cattaraugus Seneca

world tree, the *scroll* or *helix*, the *sun*, the *circle*, the *horn* and the *serpent* symbols were predominant. In connection with this research has been the study of pictographs and decorative motifs.

At the commencement of our plans for the Governor Myron H. Clark Hall of Iroquois Ethnology, when the costuming of some forty casts of Indians became a problem for consideration, it was found that no description of the Iroquois costume through the various periods existed. It became necessary to make a special study of the subject not only from books but from the Indians themselves. By good fortune many valuable notes were obtained and we may now represent with a degree of accuracy the various costumes of the Iroquois. Some of the existing pictures of Iroquois costumes are erroneous, the peace garments and war costume being represented together.

The dressing of the hair, the face painting and tattooing are other important details that have been studied with enlightening results.

Manuscripts and codes. Among much interesting matter one important manuscript has come into the possession of the division. This is the Dekanawidch code of the Iroquois by Seth Newhouse, a Canadian Mohawk. Mr Newhouse has for twenty years been compiling the manuscript, which treats of the Hiawatha legend and the Iroquois constitution. Horatio Hale, in his "Book of Rites," mentions the constitution but it is believed that it has not heretofore



Group of Six Nations chiefs in their council hall at Ohsweken, Ontario. In governmental policy the Canadian Iroquois still adhere to the old Hiawatha law.

been available in manuscript form. The essential accuracy of the document is attested by a similar manuscript compiled by the chiefs of the Six Nations of Canada, the two being written independently. The codes have been transmitted by word of mouth for generations. The Newhouse version is written in Indian-English and affords a quaint example of the transcription of Indian thought and concept into English, a most difficult thing to do at best as translators agree.

Some additional notes on the Handsome Lake religion were made and also on the various folk cults. The study of signs, omens and charms has been continued.

ARCHEOLOGY

Owing to the pressure of other work it was not possible for the Archeologist to visit the field for archeological work until late in July, when about ten days were spent in examining certain sites in

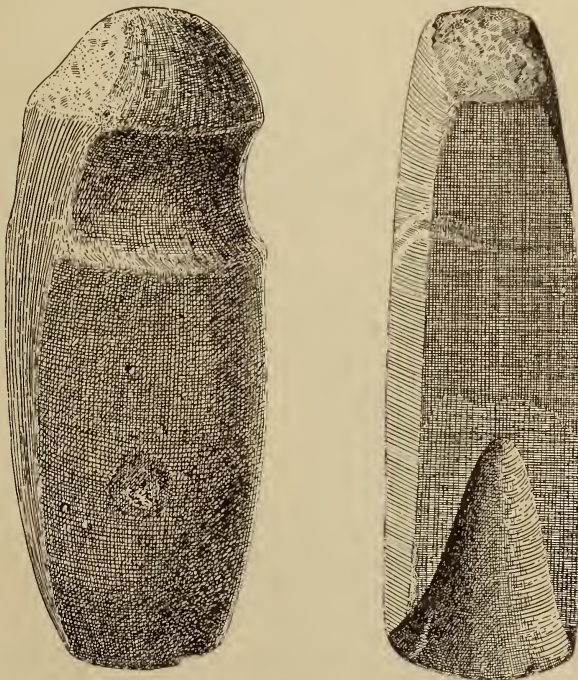


Fig. 5, 6 Grooved axe and gouge from Silver Lake. Three-fifths natural size.
Collected by N. T. Clarke

Jefferson and St Lawrence counties. Here ten or more places were visited. Most, if not all, of the described sites known to literature have been destroyed and in some it was not even possible to obtain

a potsherd or flint chip. Nearly a week was spent in the vicinity of Black lake, where a thorough survey was made. Two pipes of probably Algonquin origin were obtained here and a wooden spoon from the bottom of the lake near The Cedars. The special assistant in archeology, Mr E. R. Burmaster, made an examination of all the islands in the lake but was unable to find traces of any large camp sites.

Some of the islands in the St Lawrence were visited, especially several in the vicinity of Hammond. Several sites were there found and a number of articles secured.

No other field work was undertaken until late in August when it was decided to make a reconnaissance of certain portions of the field with the idea of obtaining a better knowledge of localities. Sites near Binghamton, Union, Windsor and Elmira were visited first. Later certain sites near Hammondsport were examined. Most of the time up to October 1st was spent in the Genesee valley.

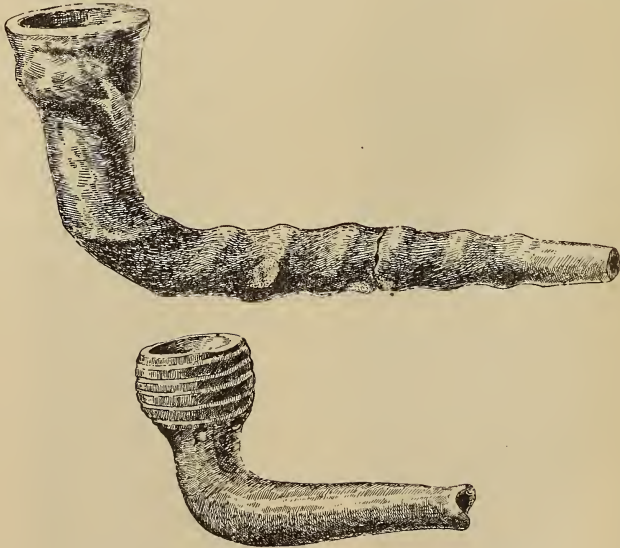
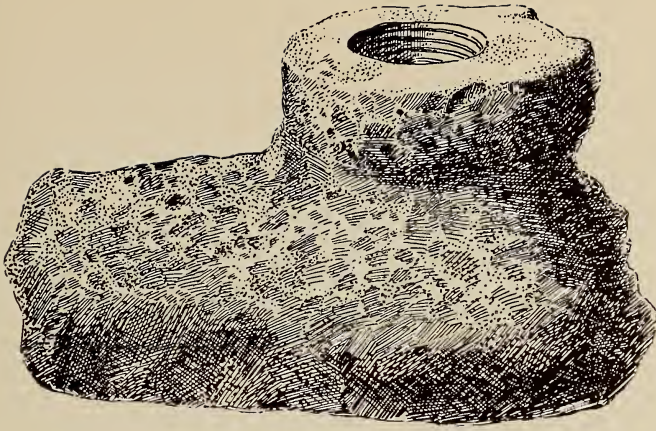


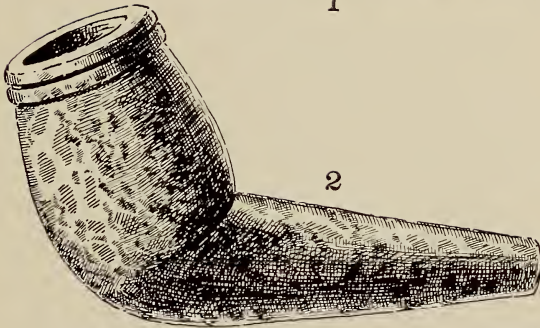
Fig. 7, 8 Clay pipes from Erie county. One-half size

Several important and productive sites were found and listed for future exploitation. Some of these sites have never been excavated, but preliminary examination revealed skeletons and extensive ash and refuse beds. A site in Erie county with which the Archeologist has been familiar for some time yielded several crushed pots that may easily be restored, several pipes and other material of interest.

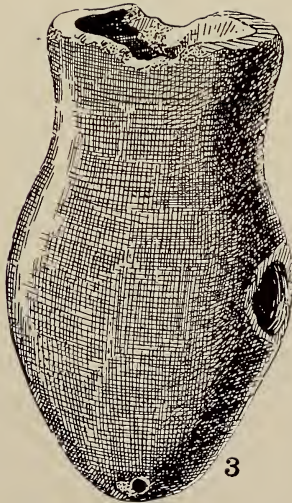
Plate 3



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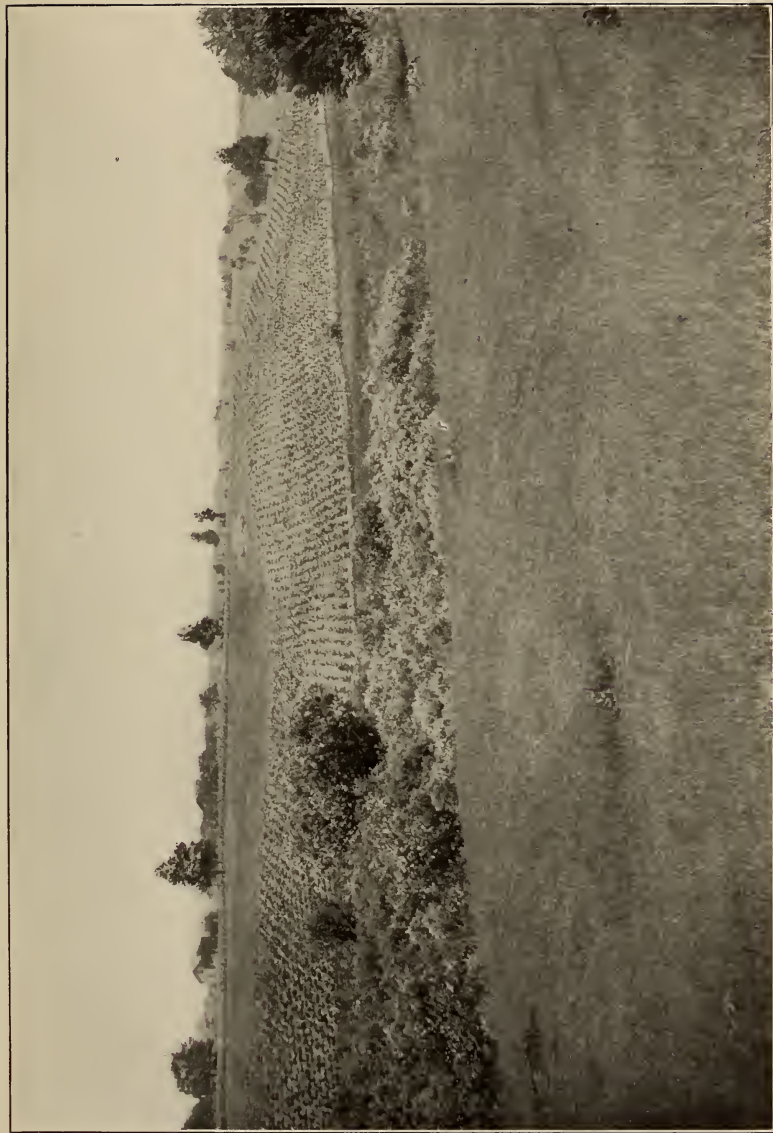
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3

Stone pipes collected during 1910. 1 Steatite pipe from Black Lake; 2 Polished steatite pipe from Edwardsville; 3 Flattened vase pipe from Pompey

Plate 4



Early Onondaga site near St Lawrence, Jefferson county. The State Museum has a large number of specimens from this site.

Several small collections of interest have been secured by gift and purchase. Among these is a collection of objects from village sites and graves in the vicinity of Pompey, obtained through Mr D. D. Luther of Naples; a collection of interesting flints, a fine gouge and a grooved axe from Silver Lake and Warsaw, obtained through Mr Noah T. Clarke; and a splendid series of smaller material and fragments from Nichols pond and Cazenovia, collected by Mr E. R. Bradley. These objects are from the ancient Oneida territory, the Nichols pond site being identified by General Clark as the fort stormed unsuccessfully by Champlain in 1615. One French axe was found there by Mr Bradley.



Fig. 9-12 Typical specimens from Nichols pond, Oneida site. This site is very probably the one which Champlain stormed unsuccessfully in 1615. Cuts full size

Archeologic frauds. The awakened interest in the relics of our aborigines and the great scarcity of fine material has led many persons to believe that the manufacture of counterfeit relics will pay. For several years the Archeologist has warned collectors and

institutions through this report; to the list of localities where frauds have been discovered he wishes to add that there are pipes from Briar Hill, St Lawrence county, and pipes and inscribed stones from Chautauqua county which are fraudulent.

A curious coincidence has led to the sending to this office of brass medals a little larger than a silver quarter, each counterparts of the other, but from different localities. One was sent from Illinois, one from Schuylerville and one from Lake George. The medals have on one side the head of an Indian and before him a war club, while the reverse has the head of an Indian woman and before her a cradle board. The workmanship of these objects is very modern, perhaps less than fifteen years, but in every case the objects have been excavated from depths and associated with Indian remains. The Lake George specimen, which was the third to come to this office, was sent by courtesy of Mr James A. Holden, treasurer of the New York State Historical Association. It had been sent to him by the finder. The specimen was attached to a brass fob and revealed the character of the specimen. The object is not Indian of course and probably no Indian ever saw one until very recently. The designs and attempts to reproduce Indian objects show a lack of familiarity with such things. The workmanship, however, is not bad and the object used as a watch fob is rather effective. Any information as to the origin of this object will be welcomed by the Archeologist.

Ethnological groups. The attention of the Archeologist has been taken up largely with plans for the ethnological groups which constitute the special feature of the Governor Myron H. Clark Hall of Iroquois Ethnology. The task of securing proper models, especially Indian females who are among the most modest of women, is no light one and calls for a great deal of tact and patience. Since the close of the fiscal year ending September 30, 1909, the Archeologist has secured models from the various Seneca and Canadian reservations and casts have been made in Buffalo and in New York. To secure Cayuga models for the Ceremonial group, the Archeologist visited the Grand River reservation and cast a series of ten typical heads. Mr D. C. Lithgow, an artist, also accompanied him and made color sketches of skin texture and color, besides paintings of heads. He also made drawings and notes on the old Iroquois architecture.

During June and July life casts of six Cayuga Indians and three Oneida Indians were made in New York by Casper Mayer, sculp-

tor. For several models the museum is indebted to Mr. F. E. Moore of Middletown, who permitted the Archeologist to engage them during the interim of the morning and evening productions of his Hiawatha play. This did much to expedite the work and special thanks is due Mr Moore for his kindness.

The Cayuga Ceremony group represents a group of members of the False Face Company and a Cayuga family within a log lodge. The period represented is late in the 18th century. Masks and the mask ceremonies are among the most striking and well-known of Iroquois ceremonies, and the abundance of material in our collections illustrating the mask rituals led to the choice of this specific subject. The Cayugas are and have been noted for their love of ceremony and ritual.

The group of casts which has been made represents a false face doctor blowing ashes through the hair of a woman as a charm against disease. One woman is seated at the rear of the lodge and holds a basket of incense. Another masked figure is seen plunging his hands in the fire for a handful of hot embers which the magic of his mask makes impotent to burn. One masked dancing figure is in the act of asking his fee of tobacco from a boy who stands frightened at one side. A large old Cayuga sits astride the singer's bench and with his turtle shell rattle beats time as he chants the ritual of his cult.

The group will be installed within an actual cabin from one of the reservations.

Of the Oneida industrial group, three figures have been secured. One is of a sleeping child, one of a woman making baskets and one of a man carving a bowl.

The painting of the backgrounds for the groups of Agriculture and Food Preparation and of the Return of the Mohawk Warriors has practically been completed. As described in my report last year, the artist, Mr D. C. Lithgow, accompanied the Archeologist into the field and made oil paintings of the scenes chosen as data for the large cycloramas. These scenes are: first, at the opening of the Genesee river as it emerges from its high banks at Mount Morris and flows northward into the broad valley, with a patch of cultivated corn land in the foreground; and second, a scene overlooking the site of the Mohawk village of Tionontogen near Sprakers in the Mohawk valley. The artist, under the direction of the Archeologist, has reproduced the village and stockade on the canvas in a manner that critics say is most commendable. The backgrounds

are not to be regarded, however, as paintings since they are to serve another purpose altogether. The foreground of the groups in which the figures will be placed will be built up to the scenic background so that the picture will really commence with the foreground and present a continuous scene. By employing a special paint which has no gloss whatever and by carefully managing the lights above, it is hoped that the illusion will be as perfect as paint and plaster can make it.

THE MARY JEMISON MONUMENT

On September 19th the Archeologist in an official capacity attended the exercises of the American Scenic and Historic Preservation Society in the unveiling of the Mary Jemison statue at Letchworth Park.

The statue, which is the gift of the lamented William Pryor Letchworth LL.D., to the State of New York, was modeled by Mr Henry K. Bush-Brown of Newburgh and represents Mary Jemison and her baby in Indian costume as they appeared after the 500 mile journey from the Ohio country to the Genesee.

Mary Jemison is known to popular history as "The White Woman of the Genesee" from her long association with the valley of that name. In 1755 when she was a mere child she was captured by a band of Seneca Indians and French adventurers, who, to prevent pursuit, killed the other members of the family except two brothers, Thomas and John, who escaped. Mary was adopted into a Seneca family and upon arriving at a marriageable age was married to She-nin-jee, a Delaware Indian who lived under the jurisdiction of the Senecas. It is the first child of this marriage who is represented on the statue in the cradle board.

Mary Jemison was called by the Seneca, Degiwenes, meaning Two Falling Voices. Most histories copy Seaver's error in orthography, calling her Deh-he-wa-mis. There is no "m" sound in the Seneca tongue.

Mary Jemison lived among the Seneca 78 years and died September 19, 1833, at the advanced age of 91 on the Buffalo creek reservation, where she was buried in the Seneca burying ground. The interesting story of this heroic woman as written by James E. Seaver from dictation by Mary Jemison herself has passed through seven editions and several of these have been issued by Mr. Letchworth.

The encroachments of civilization threatened the destruction of the old burying ground and in order to preserve her remains William

Pryor Letchworth had them removed, on March 7, 1874, at his own expense to his estate, Glen Iris, at the falls of the Genesee. Here he erected a marble monument and surrounded the new resting place with the headstones from a Seneca graveyard which had been used as a culvert by a road contractor. Doctor Letchworth removed the stones, built a new culvert and set these old markers deep in the soil about the grave of Mary Jemison so that the tops project a few inches above the ground.

A lifelong study of Mary Jemison led to Doctor Letchworth's conception of a bronze memorial statue. In its preparation by the sculptor the Archeologist was able to assist by furnishing notes and suggestions as to the costume and other accessories. The artist, however, preferred the long flowing plain type of dress not only as a more graceful garment but as a symbol of the west from which Mary journeyed in her travel to the Genesee.

The statue was unveiled on the 67th anniversary of Mary Jemison's death. A number of prominent people from all parts of the State were present and many representatives of local historical societies attended.

At the appointed hour the meeting was called to order by Hon. Charles M. Dow, chairman of the Letchworth Park committee of the American Scenic and Historic Society. Prayer was offered by Rev. L. A. Pierson of Castile. Mr Dow gave an address in which he gave a history of the park and its gift to the State by Doctor Letchworth.

George F. Kunz Ph.D. D. Sc., president of the Society, in a masterful address, spoke of the duty of preserving the picturesque places of our country. He mentioned the State's work at Watkins Glen, Niagara Falls, Stony Point and the Hudson River palisades. Glen Iris or Letchworth Park, he said, was one of the most beautiful spots in New York State. He expressed the appreciation of the people for its gift to them, and assured Doctor Letchworth that the society which he represented would prove faithful to its trust.

Doctor Letchworth responded in a short address, in which he expressed his satisfaction for the hearty interest of all concerned. He handed to Secretary E. Hagaman Hall a letter, in which he conveyed the statue to the State.

The Archeologist, who had been invited by Doctor Letchworth and the American Scenic and Historical Preservation Society to assist in the unveiling, was introduced by Secretary E. H. Hall and asked to give a short address, which follows:

Ladies and Gentlemen: In considering the position of an Indian woman in her tribe, most of us are, no doubt, influenced by the conventional schoolbook description which, I assure you, is most misleading as applied to the Iroquois. Lest you pity her too much and pity the condition of a captive white woman, permit me first to say that embodied in the constitution of the Confederacy of the Five Nations we find recorded in most emphatic language a recognition of the nobility of womanhood. Those sterling qualities that under stress bring out the wonderful moral courage of woman never received greater appreciation than that given by the Iroquois Indian.

Though as a cosharer in the burdens of life, woman labored in lodge and in field, through her council speaker her voice rang out with authority in the Confederate senate, and no warrior, no chief, no sachem, ever rose to so high a position that he could disregard it with impunity. Man might be the hunter, the forester, the warrior, the statesman, but woman was the bulwark and foundation of Iroquois society and government. As the court of the last resort in all important matters she was man's political superior.

Such was the position of woman in the aboriginal Empire State.

During the tragic events of a border conflict in which the Iroquois found himself plunged, face to face, he struggled with a powerful invader whose unfamiliar agencies of offence he could only match with his own desperate devices; snatched from her parents, there came to the Seneca-Iroquois a little captive white girl. Startled and crushed at first, she splendidly rallied. Among them she grew to maidenhood and, as the wife of an Indian, to motherhood. Singularly tried by circumstances she remained ever a woman whose pure impulses, never sullied, were ever directed to justice and charity. Her life was a leavening influence to the people of her adoption and its nobility excited their admiration and reverence.

Worthy of marble and bronze is the White Woman of the Genesee! Worthy is she because of the fortitude, the patience, the tender sympathy, the motherly devotion which she ever exhibited even in the most trying circumstances. Her wonderful moral courage, her modesty, her heroism and her gentle heart compel our appreciation and reverence.

It is with such emotions that Mrs Kennedy (Gawennois), a descendant of Mary Jemison of the fourth generation, and Miss Carolina Bennet (Gaoyowas), of the sixth generation, and I, a descendant of the people among whom she dwelt, unveil to you this bronze statue of Mary Jemison, known to the Seneca Indians as Degiwenes of the Heron clan.

Amidst these scenes so near those of her life, her sorrows and her smiles, she gazes forth into the beautiful valley.

A legend of old tells that the Sun God in passing over this spot always paused to view these wondrous falls, to watch the play of the rainbow and to inspect the mighty seam in the rock. Who knows but that, as the ancient story tells, the Sun Spirit lingers again

with us in this rare spot to look upon this fitting tribute of an appreciative heart to a noble woman, Mary Jemison, the White Captive of the Genesee!

The monument was then unveiled.

Assisting with the Archeologist in the unveiling was Mrs Thomas Kennedy, daughter of "Buffalo" Tom Jemison, the grandson of the child represented on the back of the statue, and Miss Carolina Bennet, a descendant of Mary Jemison of the sixth generation and granddaughter of the celebrated runner, Deerfoot.

The statue was draped with the American flag, which entirely concealed it. The cords were arranged at each side so that when lifted the flag rose like a butterfly above the beautiful bronze image. The people arose to their feet amidst great applause. The wonderful majesty of the girlish figure arrayed in Indian garb, her sweet Scotch-Irish face showing in every line a story of her struggle to carry her babe and herself on foot through the narrow forest paths, impressed every one. The sculptor had interpreted his subject in a sympathetic, masterful way. The figure is about nine feet high.

Charles D. Vail LL.D., of Geneva, a trustee of the Scenic Society, spoke of the value of art in preserving the great traditions of history and expressed his appreciation of Doctor Letchworth's work. Professor Vail read a letter from the sculptor, Mr Bush-Brown, describing the ideal which he had endeavored to embody in the statue.

Prof. Liberty H. Bailey of Cornell University and a trustee of the Society spoke on the outdoor ideal and paid a tribute to Doctor Letchworth's love of the beautiful in nature.

Mr James N. Johnson, the "dean poet" of Buffalo, made a few extemporaneous remarks in which he said that more poetry had been written of Glen Iris than any other spot in America, "but then," he said, "it is easy to write poetry about Glen Iris."

Rev. H. A. Dudley of Warsaw, who had once seen Mary Jemison as she passed through the Genesee valley in 1831, said that it was as a school boy that he saw her. He had a bundle of books under his arm and was passing down the road when he saw a wagon, driven by Indians, halt. Peering over the back he saw within an aged woman lying on a mattress. The woman who was

Mary Jemison looked up and greeted him pleasantly. "Where are you going?" she asked in English; "To school," he answered lifting up his books. "That is right," she answered, "learn all you can and be a good boy." Mary Jemison was at that time 89 years of age.

In the Albany *Knickerbocker-Press* of September 25th, the following description of the closing ceremonies appeared:

Perhaps the most interesting part of the unveiling was that which only a dozen persons saw.

When the crowd had dispersed Mr Parker called a chosen few together to participate in the Indian dedicatory rite. Mr J. N. Johnson, the Irish poet and an Irishman from Mary Jemison's parents' country; Miss Bishop, the secretary to Mr Letchworth, with Miss Howland, his niece; Mrs Kennedy and Miss Bennet, the two Indian descendants of Mary Jemison, and Mr Parker, gathered about the grave, which lies at the foot of the statue. Miss Bennet shelled from the cob four handfuls of native-grown Indian corn, scattering each handful as she shelled it upon the grave as a symbol of immortality. Mrs Kennedy, as an older descendant, gave a short address in the Seneca tongue. She then asked Mr Parker to light the grave fire and give the Ha-yaut-wat-gus offering. Mr Parker did so, lighting the fire from four sides, and repeating the ancient graveside rite of the Senecas. As the smoke arose to the sunny sky, Mrs Kennedy led away the company, whom she asked to look back once to see the still ascending smoke.

Mr Parker has promised to explain the symbolism of this strange old ceremony in a report to the Letchworth Park committee. It was indeed a most impressive rite, and one not seen for many years, now being known only to the Canadian Iroquois.

The monument was dedicated on September 19th, just sixty-seven years after Mary Jemison's death.

Letchworth Park lies on both sides of the Genesee river, fifty miles south of Rochester, and embraces the three falls of the Genesee. As a spot of great natural beauty, it rivals Watkins Glen and is visited by hundreds of excursionists each month.

In order to preserve this region from the ravages of commercial interests and conserve the park, Mr Letchworth in 1906 deeded it to the State. It is still his property, but nominally under the jurisdiction of the American Scenic and Historic Preservation Society.

A crude scar, as despoiled by lumbermen, Mr Letchworth has spent a lifetime in beautifying it.

The statue of Mary Jemison is his latest effort to beautify and add interest to it. The old Caneadea Indian council house stands on one side, her daughter's log cabin on the other, and Mary Jemison in bronze gazes forth into the future which none of us may know.

VII

PUBLICATIONS

A list of the scientific publications issued during the year 1909-10, with those now in press and treatises ready for printing, is attached hereto. The publications issued cover the whole range of our scientific activities. They embrace 2051 pages of text, 286 plates and 17 maps.

The labor of preparing this matter, verifying, editing and correcting is onerous and exacting. Taken altogether, it excellently indicates the activity and diligence of the staff of this division.

ANNUAL REPORT

1 Sixth Report of the Director, State Geologist and Paleontologist for the fiscal year ending September 30, 1909. 230p. 41pl. 2 maps. 4 charts.

Contents:

Introduction	the Mohawk Valley. E. O. ULRICH & H. P. CUSHING
I Condition of the scientific collections	Symmetric Arrangement in the Elements of the Paleozoic Platform of North America. RUDOLF RUEDEMANN
II Report on the geological survey	Origin of Color in the Vernon Shale. W. J. MILLER.
Geological survey	Downward Overthrust Fault at Saugerties, N. Y. G. H. CHADWICK
Seismological station	Joint Caves of Valcour Island—Their Age and Their Origin. G. H. HUDSON
Mineralogy	Contributions to Mineralogy. H. P. WHITLOCK
Paleontology	The Iroquois and the Struggle for America. ELIHU ROOT
III Report of the State Botanist	Nun-da-wa-o, the Oldest Seneca Village. D. D. LUTHER
IV Report of the State Entomologist	Index
V Report on the zoology section	
VI Report on the archeology section	
VII Publications	
VIII Staff	
IX Accessions	
Age and Relations of the Little Falls Dolomite (Calciferous) of	

MEMOIRS

2 No. 12 Birds of New York, volume 1. By E. Howard Eaton. Introductory chapters: local lists, water birds and game birds. 501p. 42 colored plates.

Contents:

Preface	Bird migration
Illustrator's note	Spring arrivals
Summary of the New York State avifauna	Published local lists
Life zones of New York State	County schedules
The Mt Marcy region	Classification
Increase and decrease of species	Descriptions of genera and species
Suggestions to bird students	Explanation of plates
	Index

3 No. 13 Calcites of New York. By H. P. Whitlock. 190p. 27pl.

Contents:

Introduction	Methods of representation
Previous work	Descriptions of occurrences
Bibliography	Theoretical conclusions
Mathematical relations and formulas	Description of plates
Symbols	Index

BULLETINS

Geology

4 No. 135 Geology of the Port Leyden Quadrangle, Lewis County, N. Y. By W. J. Miller. 62p. 11pl. map.

Contents:

Introduction	Pleistocene (glacial) geology
General geologic features	Ice erosion
Topography and drainage	Paleozoic rocks
Precambrian rocks	Structural geology
Paleozoic overlap	Economic products
Surface of the Precambrian rocks	Index

5 No. 137 Geology of the Auburn-Genoa Quadrangles. By D. D. Luther. 36p. map.

Contents:

Formations in ascending order	Devonic (<i>continued</i>)
Siluric	Ludlowville shale
Camillus shale	Tichenor limestone
Bertie waterlime	Moscow shale
Cobleskill limestone	Tully limestone
Rondout waterlime	Genesee black shale
Manlius limestone	Genundewa limestone
Devonic	West River dark shale
Oriskany sandstone	Cashaqua shale
Onondaga limestone	Hatch shales and flags
Marcellus black shale	Grimes sandstones
Cardiff shales	West Hill flags and shales
Skaneateles shale	Index

6 No. 138 Geology of the Elizabethtown and Port Henry Quadrangles. By J. F. Kemp and Rudolf Ruedemann. 176p. 20pl. 3 maps.

Contents:

Introduction
 Chapter 1 Introduction
 Chapter 2 Physiography
 Chapter 3 General geology
 Grenville series
 Chapter 4 General geology (continued)
 Metamorphosed eruptives
 Granites and related types
 Anorthosites
 Intermediate gabbros demonstrably later than the anorthosites
 Syenite series
 Basic gabbros
 Unmetamorphosed basaltic dikes
 Chapter 5 Paleozoic strata

Chapter 6 Structural geology
 Faults
 Chapter 7 Areal distribution
 Chapter 8 Areal distribution and general structure of the Paleozoic formations
 Chapter 9 Glacial and post-glacial geology
 Chapter 10 Economic geology
 1 Iron ores
 2 Limestones
 3 Clay
 Chapter 11 Mineralogy
 Bibliography
 Index

7 No. 142 The Mining and Quarry Industry of New York State. By D. H. Newland. 98p.

Contents:

Preface
 Introduction
 Mineral production of New York
 Some limitations of the mining field in New York State
 Cement
 Clay
 Production of clay materials
 Manufacture of building brick
 Other clay materials
 Pottery
 Crude clay
 Emery
 Feldspar
 Garnet
 Graphite
 Gypsum
 Iron ore
 Millstones

Mineral paint
 Mineral waters
 Natural gas
 Petroleum
 Pyrite
 Salt
 Sand
 Sand-lime brick
 Slate. HENRY LEIGHTON
 Stone. HENRY LEIGHTON
 Production of stone
 Granite
 Limestone
 Marble
 Sandstone
 Trap
 Talc
 Index

8 No. 143 Gypsum Deposits of New York. By D. H. Newland and Henry Leighton. 94p. 20pl. 4 maps.

Contents:

<ul style="list-style-type: none"> Introduction History of the gypsum industry in New York Composition and characters of gypsum Uses of gypsum General geology Details of the distribution of gypsum in New York Character of the gypsum in New 	<ul style="list-style-type: none"> York; chemical analyses Permanence of the gypsum supply Methods of prospecting and exploiting the gypsum deposits Origin of gypsum Properties of gypsum and theory of its transformation to plasters Technology of gypsum plasters Bibliography Index
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9 No. 145 Geology of the Thousand Islands Region. By H. P. Cushing, H. L. Fairchild, Rudolf Ruedemann and C. H. Smyth, Jr. 1949. 62p. 6 (5 colored) maps.

Contents:

<ul style="list-style-type: none"> Introduction Location and character Summary of geologic history <ul style="list-style-type: none"> Igneous intrusions Close of the long period of erosion Paleozoic sediments Subsequent history of the region The Pleistocene The rocks <ul style="list-style-type: none"> Precambrian rocks Great Precambrian erosion Paleozoic rocks <ul style="list-style-type: none"> Precambrian surface underneath the Potsdam Potsdam sandstone Theresa and Tribes Hill formations Pamelia formation Mohawkian series Summary of Paleozoic oscillations of level <ul style="list-style-type: none"> Dip of the Paleozoic rocks Rock structures <ul style="list-style-type: none"> Foliation Joints Folds Faults Topography 	<ul style="list-style-type: none"> Paleozoic altitude and climate Amount of erosion Original drainage Tertiary uplift Tertiary drainage Plateaus, terraces, scarps Lakes Underground drainage Pleistocene geology <ul style="list-style-type: none"> History Physiography Glacial deposits Glacial erosion Prewisconsin glaciation Economic geology <ul style="list-style-type: none"> Road metal Granite quarries Sandstone quarries Limestone quarries Petrography of some Precambrian rocks <ul style="list-style-type: none"> Bleached granite Picton granite Alexandria syenite Granitized amphibolite and amphibolized granite (soaked rocks) Index
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Entomology

10 No. 136 Control of Flies and Other Household Insects. By Ephraim Porter Felt D.Sc. 56p.

Contents:

Introduction	Clothes moths
Disease carriers	Carpet beetles
Typhoid or house fly	Silver fish, bristle tail or fish
Fruit flies	moth
Malarial mosquito	Book louse
Yellow fever mosquito	White ants
Bedbug	Crickets
Annoying forms	Food pests
Cluster fly	House ants
Wasps and hornets	Cockroaches
House or rain barrel mosquito	Larder beetle
Salt marsh mosquito	Cheese skipper
House fleas	Cereal and seed pests
Bedbug hunter	Fumigation with hydrocyanic acid
House centipede	gas
Fabric pests	Index

11 No. 141 Report of the State Entomologist for the fiscal year ending September 30, 1909. 116p. 10pl.

Contents:

Introduction	Shade tree pests
Injurious insects	Forest insects
Typhoid or house fly	Publications of the Entomologist
Brown tail moth	Additions to collections
Codling moth	Insect collections
Hickory leaf stem borer	Insect types in New York State
Rhododendron lace bug	Museum
Plant lice	Additional lists of Adirondack in-
Notes for the year	sects. D. B. YOUNG
Fruit tree pests	Explanation of plates
Small fruit insects	Index
Miscellaneous	

Botany

12 No. 139 Report of the State Botanist for the fiscal year ending September 30, 1909. 116p. 10pl.

Contents:

Introduction	Species not before reported
Plants added to the herbarium	Remarks and observations
Contributors and their contribu-	Edible fungi
tions	New species of extralimital fungi

New York species of *Inocybe*
 New York species of *Hebeloma*
 List of edible, poisonous and un-
 wholesome mushrooms hitherto
 figured and described by C. H.
 Peck

List of genera whose New York
 species (chiefly) have been col-
 lated with descriptions in the
 State Botanist's reports cited
 Explanation of plates
 Index

Archeology

13 No. 144 Iroquois Uses of Maize and Other Food Plants. By
 Arthur C. Parker. 120p. 31pl.

Contents:

Preparatory note

Part I Maize

I Maize or Indian corn in his-
 tory

II Early records of corn culti-
 vation

III Customs of corn cultivation

IV Ceremonial and legendary
 allusions to corn

V Varieties of maize used

VI Corn cultivation terminology

VII Utensils for the preparation
 of corn for food

VIII Cooking and eating customs

IX Foods prepared from corn

X Uses of the corn plant

Part 2 Other food plants

XI Beans and bean foods

XII Squashes and other vine
 vegetables

XIII Leaf and stalk foods

XIV Fungi and lichens

XV Fruit and berrylike foods

XVI Food nuts

XVII Sap and bark foods

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16 Elizabethtown-Port Henry Quadrangles

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18 Eurypterida of New York

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Geology

19 Geology of New York City (Catskill) Aqueduct

20 Geology of the Poughkeepsie Quadrangle

21 Geology of the Honeoye-Wayland Quadrangles

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VIII

STAFF OF THE SCIENCE DIVISION AND STATE MUSEUM

The members of the staff, permanent and temporary, of this division as at present constituted are:

ADMINISTRATION

John M. Clarke, Director
Jacob Van Deloo, Director's clerk

GEOLOGY AND PALEONTOLOGY

John M. Clarke, State Geologist and Paleontologist
David H. Newland, Assistant State Geologist
Rudolf Ruedemann, Assistant State Paleontologist
C. A. Hartnagel, Assistant in geology
Robert W. Jones, Assistant in economic geology
D. Dana Luther, Field Geologist
Herbert P. Whitlock C. E., Mineralogist
George S. Barkentin, Draftsman
Joseph Morje, First clerk
H. C. Wardell, Preparator
Dudley B. Mattice, Stenographer
Martin Sheehy, Machinist.
Joseph Bylancik, Page

TEMPORARY ASSISTANTS

Areal geology

Prof. H. P. Cushing, Adelbert College
Prof. J. F. Kemp, Columbia University
Dr C. P. Berkey, Columbia University
Dr Arthur Hollick, Bronx Garden
G. H. Hudson, Plattsburg State Normal School
Prof. W. J. Miller, Hamilton College
Burton W. Clark, Washington, D. C.

Geographic geology

Prof. Herman L. Fairchild, Rochester University
 Prof. Albert P. Brigham, Colgate University

Paleontology

Edwin Kirk, Washington, D. C.

BOTANY

Charles H. Peck, M. A., State Botanist
 Stewart H. Burnham, Assistant, Glens Falls

ENTOMOLOGY

Ephraim P. Felt, B. S. D.Sc., State Entomologist
 D. B. Young, Assistant State Entomologist
 Fanny T. Hartman, Assistant
 Anna M. Tolhurst, Stenographer
 J. Shafer Bartlett, Clerk

ZOOLOGY

Willard G. Van Name, Ph.D., Zoologist
 Arthur Paladin, Taxidermist

Temporary assistants

Prof. E. Howard Eaton, Canandaigua
 Dr H. A. Pilsbry, Philadelphia

ARCHEOLOGY

Arthur C. Parker, Archeologist

IX

ACCESSIONS

ECONOMIC GEOLOGY

Collection

Newland, D. H. Albany	
Iron ores and wall rocks from Gellivare and Kiruna, Sweden....	10
Jones, R. W. Albany	
Large rose quartz, Bedford	1
Limonite ore, Ancram	5
Slabs of brecciated limestone, Hudson	2

Block of augen-gneiss, Bedford.....	1
Feldspar, Bedford	4
Iron carbonate, Greendale	4
	<hr/>
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PALEONTOLOGY

*Donation***Springer, Frank.** Burlington, Ia.

Type of <i>Squamaster echinatus</i> Ringueberg, Niagara shales, Lockport, N. Y.....	1
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The Geologic and Mineralogic Service, Brazil

Devonic fossils from the State of Parana, Brazil.....	104
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*Purchase***Halle, Dr Thomas.** Stockholm, Sweden

Collection of Devonic fossils from the Falkland Islands sandstone, Falkland Islands.....	128
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Plourde, Antony. Migouasha West, Province of Quebec, Canada

Devonic fishes from Migouasha, Canada.....	333
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*Collection***Clarke, John M.**

Devonic and Siluric fossils from Percé, Province of Quebec, Canada.	56
Devonic and Siluric fossils from Migouasha, Canada.....	25
Devonic fossils from Dalhousie, N. B., Canada.....	125
Fossil fish from Devonic fish beds near Migouasha, Province of Quebec, Canada.....	12

Hartnagel, C. A.

Devonic fossils from near Three Forks, Mont.	2000
Carboniferous fossils from Quadrant and Madison formations near Logan, Mont.	

Jones, R. W.

Trilobite (<i>Proetus protuberans</i>) from New Scotland beds near Catskill.....	1
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Luther, D. D.

Crinoids and starfishes from Grimes sandstone, near Naples, N. Y.	200
Crinoids from Portage formation near Laona and Griswolds	23

Ruedemann, R.

Fossils from Frankfort shale, Utica shale, Trenton limestone at various localities	2000
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Wardell, H. C.

Frankfort shale fossils from Detbone quarry between Schenectady and Aqueduct	400
Frankfort shale fossils from gully two miles east of Rotterdam Junction	40
Frankfort shale fossils from near Delanson	50

MINERALOGY

Donation

D. H. Newland, Albany	
Native lead, Langban, Sweden	2
Melanotekite, Langban, Sweden	1
Gadolinite, Iveland, Norway	1
Rutile and albite, Gjorestad, Norway.....	1
Rutile, Gjorestad, Norway	5
Pinakiolite, Langban, Sweden	1
Uraninite (Bröggerite), Sätersdalen, Norway.....	1
Manganophyllite, Langban, Sweden	1
Thorite, Arendal, Norway	1
Aeschnyite, Iveland, Norway	1
Apatite, Gellivare, Sweden	4
Euxenite, Iveland, Norway	1
Columbite, Iveland, Norway	1
Monazite, Risör, Norway	1
R. W. Jones, Albany	
Copper and malachite, Elco co., Nevada	1
Pyrite, Boulder co., Colorado	1
H. P. Whitlock, Albany	
Microcline, Niantic, R. I.	5
Albite, Niantic, R. I.	4
Muscovite in microcline, Niantic, R. I.....	3
Beers, Charles H. New York city	
Calamine (cut), Chihuahua, Mexico	1
Manchester, J. G. New York city	
Autunite on cyrtolite, Bedford	1
Kelly, F. W. Albany	
Calcite (stalactite), Howes Cave	1
Blumenthall, M. Lockport	
Sphalerite, Lockport	1
Celestite, Lockport	1
Calcite and dolomite, Lockport	1
Gypsum, Lockport	2
Hulett, W. H. East Greenbush	
Pyrite crystals, Bloomingrove, Rensselaer co.	17
Wallace, J. J. Gouverneur	
Pyrite in talc, Fowler	2

Exchange

University of Toronto Museum, Toronto, Canada	
Sodalite, Sodalite Creek, B. C.	1
Wernerite, Cardiff Township, Ont.	1
Pentlandite, Vermillion Mine, Sudbury, Ont.	1
Niccolite, Cobalt, Ontario	1
Smaltite, Cobalt, Ontario	1
Native silver, Cobalt, Ontario	1

Native bismuth, Cobalt, Ontario	1
Ulexite on gypsum, Wentworth, N. S.	1
Howlite, Wentworth, N. S.	2
Chalcocite, Tatamagauche, N. S.	3
Corundum, Salem, India	4
Pyromorphite, Moyie, B. C.	1
Erythrite, Creston, B. C.	1
Native gold, Larder Lake, Ont.	1
Analcite, Two Islands, N. S.	1
Chabazite, Two Islands, N. S.	1
Barite, Five Islands, N. S.	1
Kermesite and stibnite, West Gore, N. S.	1
Native antimony, West Gore, N. S.	1

Purchase

Beers, Charles H. New York city	
Calamine, Chihuahua, Mexico	10
Calamine (cut), Chihuahua, Mexico	6
Malachite and chrysocolla, Chihuahua, Mexico	5
Malachite and chrysocolla (cut), Chihuahua, Mexico	2
Malachite, Chihuahua, Mexico	5
Quartz (cut), Chihuahua, Mexico	3
Obsidian, Chihuahua, Mexico	1
Obsidian (cut), Chihuahua, Mexico	1
Jones, Ch. H. New York city	
Calcite, Kelly Island, Ohio	18
Calcite (loose crystals), Kelly Island, Ohio	23
Calcite, Tiffin, Ohio	1
Calcite, Genoa, Ohio	1
Krantz, F. Bonn, Germany	
Model of Cullinan diamond (glass)	1
Models of Cullinan diamond cuttings (glass)	9
Schmidt, A. A. Albany	
Sphalerite (polished), loc.?.....	1
Quartz (agate), (polished), loc.?.....	2

Collection

Whitlock, H. P. Albany	
Tourmalin in quartz, New York city.....	2
Pyrite in dolomite, New York city	2
Muscovite in pegmatite, New York city	9
Pyrolusite (dendrite) on microcline, Bedford	3
Autunite on cyrtolite, Bedford	3
Cyrtolite, Bedford	2
Quartz (rose), Bedford	8
Quartz (rose), cut	2
Microcline (crystals), Bedford	18
Microcline crystals in quartz, Bedford ...	10
Beryl, Bedford	16
Quartz in microcline, Bedford.....	1
Tourmalin in quartz, Bedford.....	1

Calcite, Becraft Mt.	6
Calcite, Greendale	15
Luther, D. D.	
Barite (concretions), Silver Creek	81

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ENTOMOLOGY

Donation

Hymenoptera

- Stillwell, S. W.** Charlotteville. *Thalessa atrata* Fabr., black long sting, adult on maple, June 13
- Kampfer, A. L.** Albany. *Thalessa lunator* Fabr., lunate long sting, adult, July 23
- Latham, Roy.** Orient Point. *Aulacidea tumidus* Bass., gall on Lactuca, August 30
- Dodge, J. H.** Rochester. Through State Department of Agriculture. *Neuroterus batatus* Fitch, galls on white oak, July 8
- Lackey, Andrew.** Johnsburg. *Lophyrus abbotii* Leach, Abbott's sawfly, larvae on pine, August 3
- Wilson, J. W.** Olmstedville. Same as preceding
- Cox, Townsend, Jr.** Setauket. *Lophyrus ? lecontei* Fitch, Leconte's pine sawfly, larvae on pine, October 20
- Post, H. S.** Albany. *Trichiocampus viminalis* Fall., poplar sawfly on poplar, August 29
- Rose, L. A.** Rensselaer. *Eriocampoides limacina* Retz., cherry and pear slug, larvae on cherry, August 22
- Dodge, J. H.** Rochester. Through State Department of Agriculture. *Harpiphorus tarsatus* Say, sawfly, larvae on *Cornus mascula*, September 15
- Rinkle, L. F.** Boonville. *Harpiphorus versicolor* Nort., sawfly, larvae on *Cornus alternifolium*, September 18

Coleoptera

- Lohrmann, Richard.** Herkimer. *Entimus imperialis* Först., diamond beetle, adult, May 7
- Schaefer, P. A.** Allentown, Pa. *Calandra granaria* Linn., granary weevil, adults in grain bins, December 27
- Frey, S. L.** Palatine Bridge. *Magdalis? barbata* Say, black elm snout beetle, grubs on elm, March 18
- Dorrance, Benjamin.** Dorranceton, Pa. Through Hermann Von Schrenk. *Pissodes strobi* Peck, white pine weevil, larvae on pine, July 13
- Von Schrenk, Hermann.** Southern California. *Phloeodes diabolicus* Lec., adult on *Polyporus* growing on Eucalyptus, March 20
- Fitch, F. A.** Randolph. *Bruchus obtectus* Say, bean weevil, adults, March 21
- Clarke, Miss L. E.** Canandaigua, *Haltica ignita* Ill., strawberry flea beetle, adults on Virginia creeper, August 3

- Clark, F. T. Ticonderoga. *Galerucella luteola* Müll., elm leaf beetle, larvae and pupae on elm, July 19
- Foulk, Theodore, Flushing. Through State Department of Agriculture. *Melasoma scripta* Fabr., cottonwood leaf beetle on poplar, September 7
- Lynch, Mrs J. DeP. Barneveld. *Centrodera decolorata* Harr., adults on locust, October 18
- Brown, H. T. Rochester. *Desmocerus palliatus* Forst., cloaked knotty horn, adults on elder, June 6
- Payne, W. A. Bronxville. *Elaphidion villosum* Fabr., maple and oak twig pruner, work on oak, July 31
- Ellison, Burton. Poughkeepsie. *Prionus laticollis* Dru., broad-necked *Prionus*, adult, July 18
- Marshall, D. T. Hollis. *Xyloryctes satyrus* Fabr., rhinoceros beetle, August 1
- Keating, J. D. Fort Edward. *Euphoria inda* Linn., bumble flower beetle, adult, September 6
- Gillett, J. R. Kingston. *Cotalpa lanigera* Linn., goldsmith beetle, adult, April 15
- Joutel, L. H. Europe. *Thanasimus rufipes* Brahm., adult, July 29
- Filer, H. B. Buffalo. *Podabrus rugosulus* Lec., adults, June 16
- Miturn, Purley. Locke. *Agriotes mancus* Say, wheat wire-worm, larvae injuring oats, May 20

Diptera

- Reist, Mrs H. G. Schenectady. *Calliphora viridescens* Desv., larvae, July 30
- Dick, H. E. A. Rochester. *Bombyliomyia abrupta* Wied., adult, July 26
- Hodges, G. C. New Hartford. *Rhyphus fenestralis* Scop., adults, April 24
- Lohrmann, Richard. Herkimer. *Bibio xanthopus* Wied., adult May 18
- Johnson, Fred. North East, Pa. *Contarinia johnsoni* Sling., grape blossom midge, adult, May 28
- Stene, A. E. Kingston, R. I. *Monarthropalpus buxi* Lab., pupa on box, May 19
- Kieffer, J. J. Bitsch, Germany. *Joanissia aurantiaca* Kieff., *Aprionus miki* Kieff., *A. pinicola* Kieff. MS., *Monardia stirpium* Kieff., *Bryomyia bergrothi* Kieff., *Miastor cerasi* Kieff. MS., *Brachyneura squamigera* Winn., *Winnertzia fusca* Kieff. MS., *W. pinicola* Kieff. MS., *Colomyia clavata* Kieff., *Colpodia anomala* Kieff., *Dicerura scirpicola* Kieff., *Porricondyla venustus* Winn., *Camptomyia* ? *binotata* Kieff., *C. nigricornis* Kieff., *Holoneurus pilosus* Kieff. MS., *Lasioptera rubi* Heeg., *Baldratia salicorniae* Kieff., *Stefaniella atriplicis* Kieff., *Trotteria*

sarothamni Kieff., Rhizomyia silvicola Kieff., Cystiphora taraxaci Kieff., Macrolabis stellariae Kieff., Arnoldia castanea Kieff. MS., A. sambuci Kieff., A. cerris Koll., Lasiopteryx (Ledomyia) divisa Kieff., L. (Ledomyia) lugens Kieff., Dasyneura sisymbrii Schrnk., D. urticae Perris, Rhabdophaga karschii Kieff., R. pierrei Kieff., Mikiola fagi Hart., Psectrosema tamaricis Stef., Schizomyia galiorum Kieff., Zeuxidiplosis giardiana Kieff., Stenodiplosis geniculati Reut., Thecodiplosis brachyntera Schw., Bremia longipes Kieff., B. ramosa Kieff., Aphidoletes urticariae Kieff., Massalonia rubra Kieff., Hormomyia cornifex Kieff., Monarthropalpus buxi Lab., Pseudhormomyia granifex Kieff., Xylodiplosis aestivalis Kieff., X. nigritarsis Zett., Putoniella marsupialis F. Lw., Endaphis perfidus Kieff., Macrodiplosis volvens Kieff., Clino-diplosis galliperda F. Lw. Especially valuable because a number are cotypes

Lepidoptera

- Carriere, Mrs.** Albany. *Sphecodina abbotii* Sm. & Abb., Abbott's sphinx, larva on woodbine, July 13
- State Department of Agriculture.** Rochester. *Saturnia pavonia* Linn., Emperor moth, cocoon on French nursery stock, January 31
- Griffith, L. C.** Through State Department of Agriculture. *Anisota senatoria* Sm. & Abb., larvae on oak, September 9
- Lackey, Andrew.** Johnsburg. *Basilona imperialis* Dru. Imperial moth, larvae on pine, August 18
- Adams, L. H.** Johnstown. Through State Department of Agriculture. *Ctenucha virginica* Charp., larvae on pine and gooseberry
- Griffith, L. C.** Lynbrook. Through State Department of Agriculture. *Halisidota caryae* Harr., hickory tussock moth, larvae on maple, July 11
- Hotaling, William.** Kinderhook. *Arsilonche albovenosa* Goeze, larva, September 27
- Anderson, Alex.** Stonyford. *Xylina antennata* Walk., green fruit worm, larvae on maple, June 16
- State Department of Agriculture.** Geneva. Same as preceding, larvae on apple, June 28
- Gordinier, H. W.** Troy. *Notolophus antiqua* Linn., rusty tussock moth, eggs, March 9
- Vaughan, H. E.** Ogdensburg. Same as preceding, caterpillars on elm, June 18
- Griffith, L. C.** Lynbrook. Through State Department of Agriculture. *Datana integerrima?* G. & R., larvae, July 11
- Perry, C. C.** Eagle Bridge. *Schizura concinna* Sm. & Abb., red-humped apple caterpillar, larvae on apple, September 10
- Capron, Louis.** Menands. *Synchlora viridipallens* Hulst., adult, August 4

- Griffith, L. C.** Sag Harbor. Through State Department of Agriculture. *Cingilia catenaria* Dru., chain-spotted geometer, larvae on sweet fern, bayberry, August 2
- Thomson, Edward.** Frost Valley, Denning. *Ennomos subsignarius* Hübn., snow-white linden moth, eggs on maple, March 28
- Ayer, J. C.** Glen Cove. Same as preceding, adult, July 22
- Bullis, W. A.** West Sand Lake. *Phobetron pithecium*. Sm. & Abb., hag moth caterpillar, larva, September 13
- Newell, H. I.** Richmond Hill. *Zeuzera pyrina* Linn., leopard moth, pupae, July 1
- Beam, T. J.** Port Chester. Through State Department of Agriculture. Same as preceding, exuviae on maple, July 5
- Serins, E. G.** South River, N. J. Through Country Gentleman. Same as preceding, larvae on apple, September 17
- Dodge, J. D.** Rochester. *Hypnomena malinella* Zell., ermine moth, larvae on imported French apple stock, June 24
- Barden, J. J.** Orleans. Same as preceding, larvae on apple, June 27
- Ham, R. H.** Niverville. *Ancylis nubeculana* Clem., larvae on apple, September 1
- Harris, S. G.** Tarrytown. *Dichomeris marginellus* Fabr., Juniper webworm, larvae on juniper, February 28
- Rhind, L. D.** Plandome. Through State Department of Agriculture. Same as preceding, larvae on Irish juniper, April 26
- Hammond, Benjamin.** Fishkill. *Aspidisca splendorifera* Clem., resplendent shield bearer, winter cases, March 24

Hemiptera

- Collins, J. D.** Utica. *Belostoma americanum* Leidy, giant waterbug or electric light bug, adult attached to a fish, May 4
- Cook, D. H.** Altamont. *Brochymena quadripustulata* Fabr., adult, July 15
- Thorne, W. P.** Lagrangeville. Same as preceding, nymphs, August 26
- Wheeler, Fred.** Mongaup Valley. Through State Department of Agriculture. *Blissus leucopterus* Say, chinch bug, nymphs on corn, August 5
- Lee, V. P. D.** Altamont. *Haematopinus piliferus* Burm., sucking dog louse, adult on dog, January 8
- Webber, Mrs C. F.** Athens. *Ormenis pruinosa* Say, lightning leaf hopper on matrimony vine, August 26. Also *Aleyrodes vaporariorum* Westw., white fly on coleus, August 26
- Briggs, F. F.** Pocantico Hills. *Chermes abietis* Linn., spruce gall aphid, galls on spruce, June 23
- Harris, S. G.** Tarrytown. Same as preceding, adults on spruce, June 26
- Fouk, Theodore.** Flushing. Same as preceding, galls on spruce, October 12
- State Department of Agriculture.** White Plains. *Chermes coolayi* Gill., galls on Colorado blue spruce, August 4
- Richardson, M. Y.** New York city. *Chermes pinicorticis* Fitch, pine bark aphid, adults on pine, May 12
- Goldenmark, Miss Pauline.** New York city. Same as preceding, eggs, February 12

- State Department of Agriculture.** Rochester. *Chermes piceae* Ratz., adults and eggs on Nordmann's fir, May 17
- Patch, Miss Edith M.** Orono, Me. *Chermes pinifoliae* Fitch, pine leaf aphid, adult on black spruce, January 29. Also *C. consolidatus* Patch, adults on larch; *C. floccus* Patch, adult on black spruce; *C. lariciatus* Patch, adults on white spruce, January 29
- Wood, G. C.** Barneveld. *Pemphigus imbricator* Fitch, beech blight, nymph on beech, August 31
- Knapp A. P.** Hillsdale, N. J. Through *Country Gentleman*. *Pemphigus tessellata* Fitch, woolly maple leaf aphid, adults on maple, June 16
- Seymour, Miss May.** Lake Placid. Same as preceding, eggs, June 20
- Boren, R. M.** Ballston Lake. *Schizoneura americana* Riley, woolly elm leaf aphid, adults on elm, June 5
- Judson, W. P.** Broadalbin. Same as preceding, adults and young on elm, June 10
- Vaughan, H. E.** Ogdensburg. Same as preceding, adults on elm, June 18
- Ashley, C. S.** Old Chatham. *Schizoneura lanigera* Hausm., woolly apple aphid, nymph on apple, November 9
- Niles, Mrs S. H.** Coeymans. Same as preceding
- Rose, J. F.** South Byron. Same as preceding, November 10
- Bell & Smith.** Castleton. Same as preceding, November 13
- Woolworth, C. C.** Castleton. Same as preceding
- Peck, C. H.** Lake Placid. *Lachnus abietis* Fitch, on balsam, September 8
- Dunbar, John.** Rochester. *Psylla pyricola* Forst., pear psylla, adults on pear, September 20
- Smith, H. B.** Nashville, Tenn. Through *Garden Magazine*, Doubleday, Page & Co., *Pachypsylla celtidis-gemma* Riley, hackberry nodule gall, galls on hackberry, February 16
- Peterson, O. W.** Fairfield county, Conn. Through *Country Gentleman*. *Eulecanium tulipiferae* Cook, tulip tree scale on tulip, August 31
- State Department of Agriculture.** *Asterolecanium pustulans* Ckll., golden oak scale, adults on oak, May 16
- Foulk, Theodore.** Flushing. Through State Department of Agriculture. *Asterolecanium variolosum* Ratz., on oak, September 7
- Beresford, Archibald.** Mt Vernon. *Phenacoccus acericola* King, false cottony maple scale, young, January 21
- Fisher, Mrs Alice G.** Batavia. Same as preceding, eggs on maple, July 18
- Dudley, Miss Fanny.** Newburgh. Same as preceding, females and young on maple, October 4
- Olsen, C. E.** Winfield. *Pseudococcus longispinus* Targ., mealy bug, February 24
- Country Gentleman.** Albany. Same as preceding, larvae on coleus, August 30
- Morley, G. W.** Haverstraw. Through State Department of Agricul-

- ture. *Pulvinaria vitis* Linn., cottony maple scale, females and young on maple, July 26
- Cockerell, T. D. A.** Boulder, Col. *Pulvinaria occidentalis subalpina* Ckll., immature, August 31
- Bard, R. H. C.** Syracuse. Through State Department of Agriculture. *Gossyparia spuria* Mod., elm bark louse on elm, July 9
- State Department of Agriculture.** Brooklyn. *Eriococcus azaliae* Comst., on azalea, November
- Husted, P. L.** Kingston. *Aulacaspis pentagona* Targ., West Indian peach scale, adult on Japanese flowering cherry, January
- State Department of Agriculture.** Same as preceding, adult on Japanese cherries, February 3
- Woolworth, C. C.** Castleton. *Aulacaspis rosae* Bouché, rose scale on rose, November 13
- Woodford, L. L.** Pompey. Same as preceding, adults on rose, April 29
- Landreth, W. B.** Schenectady. *Chionaspis americana* John., elm scurfy scale, crawling young, May 10
- Hechler, C. H.** Roslyn. *Chionaspis euonymi* Comst., euonymus scale, eggs on ? *Euonymus*, May 19
- State Department of Agriculture.** Long Island. *Fiorinia fioriniae* var. *japonica* Kuw., adults on Japanese hemlock, June 9

Orthoptera

- Ashley, N.** Old Chatham. *Chortophaga viridifasciata* DeG., green-striped grasshopper, nymphs, March 26

Exchange

- Bezzi, Mario.** Torino, Italy. Galls of *Cystiphorasonchi* F. Lw., *Dryomyia circinans* Gir., *D. lichtensteinii* F. Lw., *Dasyneura sisymbrii* Schrnk., *Perrisia*¹ sp., *P. alpina* F. Lw., *P. capitigena* Br., *P. crataegi* Winn., *P. ericina* F. Lw., *P. fraxini* Kieff., *P. oenophila* Haimh., *P. pustulans* Rubs., *P. rosarum* Hdy., *P. salicariae* Kieff., *P. ulmariae* Br., *Rhabdophaga rosaria* H. Lw., *Mikiola fagi* Hart., *Rhopalomyia artemisiae* Bouché, *Oligotrophus* sp., *O. capreae* Winn., *O. corni* Gir., *O. reaumurianus* F. Lw., *O. solmsii* Kieff., *O. taxi* Incb., *Mayetiola poae* Bosc., *Asphondylia* sp., *A. sarothamni* H. Lw., *Schizomyia pimpinellae* F. Lw., *Harmandia petioli* Kieff., *H. tremulae* Winn., *Clinodiplosis vaccinii* Kieff.

ZOOLOGY

Donation

Mammals

- Corbin, Austin,** President. Blue Mountain Forest Association. Buffalo, calf, *Bison bison* (Linnaeus), skin..... 1
- Klein, A. J.** Albany. New York weasel, *Plutorius noveboracensis* (Emmons) skins 2

¹A synonym for *Dasyneura*.

- Latimer, G. S.** Masonville. Black squirrel, *Sciurus carolinensis leucotis* (Gapper) skin..... 1
Peck, Dr Chas. H. Albany. Little brown bat, *Myotis lucifugus* (Le Conte) skin 1

Birds

- McKinley, J. D.** Loudonville. Holboell grebe, *Colymbus holboelli* (Reinhardt) skin 1

Reptiles

- Burmester, E. R.** Irving. Puffing adder, *Heterodon platyrhinos* Latreille, spec..... 1

Amphibians

- McCann, Mrs.** Albany. Tiger salamander, *Ambystoma tigrinum* (Green), spec. 1

Fishes

- Bean, Dr T. H.** Albany. Steelhead trout, *Salmo gairdneri* Richardson, spec. 1

Purchase

Mammals

- Paladin, Arthur.** Albany. Gray fox, *Urocyon cinereoargentatus* (Schreber), spec. 2
Prest, F. L. Grosse Isle, Magdalen Islands.
 Harbor seal, *Phoca vitulina* (Linnaeus), skin..... 1

Birds

- Gowie, Mr.** Albany. Screech owl, *Otus asio* (Linnaeus), skins. 5

Casts of reptiles

Ward's Natural Science Establishment. Rochester.

- Brown snake, *Storeria occipitomaculata* (Storer).. 1
 Garter snake, *Thamnophis sirtalis sirtalis* (Linnaeus).. 1
 Blue-tailed lizard, *Eumeces fasciatus* (Linnaeus) 1
 Leather turtle, *Amyda mutica* (Le Sueur) 1
 Soft-shelled turtle, *Aspidonectes spinifer* (Le Sueur).. 1

Casts of amphibians

- Mud puppy, *Necturus maculosus* Rafinesque 1
 Hellbender, *Cryptobranchus alleganiensis* (Daudin).. 1
 Spadefoot toad, *Scaphiopus holbrooki*, Harlan 1

Mollusks

- Marvin, Dwight.** Greenwich. The Ingalls collection of shells. These have not been fully sorted or cataloged; an estimate of their number left by Mr Ward is as follows:

Gastropoda	3500	
Pelecypoda	5000	
Pulmonata	15500	
		24000
Total		24000

24025

ARCHEOLOGY

Excavation

By **A. C. Parker** and **E. R. Burmaster**

Golah, Monroe county

Arrowheads	51
Flint drills.....	2
Pipe bowl fragment.....	1
Bone awl.....	1

Brant, Erie county

Hammer stones.....	5
Arrowheads	81
Stone metate.....	1
Pipe, terra cotta.....	1
Clay pots, crushed.....	2
Clay pots, nearly entire.....	2
Stone celts.....	7
Flint knives.....	2
Serrated slate arrowhead.....	1
Brass arrowheads	8
Brass kettle bail.....	1
Bone tubes.....	40
Bone tubes (human leg bones).....	6
Potsherds	50
Celts	7
Celts in process.....	2
Shell beads.....	5
Wampum beads.....	40
Iron trade axes.....	2
Bark cloth fragment.....	1

Ripley, Chautauqua county

Pottery vessel, entire.....	1
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Edwardsville, St Lawrence county

Pipes, stone.....	2
Gorget, pendant.....	1
Potsherds	20

Lima, Ontario county

Wolf's tooth, perforated.....	1
Gorget	1

Chenango Forks, Broome county

Soapstone bowl fragments.....	3
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Stone hoes.....	2
Pottery fragments.....	10
St Lawrence, Jefferson county	
Potsherds	32
Spear head.....	1
Animal bones, box.....	1
Flint knife	1
Hammondsport, Yates county	
Stone bar.....	1
Net sinkers.....	25
Hammer stones	6
Celts, crude.....	2
Arrowheads	5
Clarke, Noah T. Albany	
From Silver Lake	
Arrowheads	3
Gouge	1
Grooved axe.....	1
Celts	2
Spear head	1
Worked stone.....	1
Dann, John. Honeoye Falls	
Hawk bells.....	3
Fragment of beaver skin.....	1
Fragment of shell gorget.....	1
Pipe stems	3

Purchase

Bradley, E. R. Cazenovia	
Atwell site, Cazenovia	
Pipe stem fragments	19
Pipe bowl fragments	14
Flints	3
Potsherds, undecorated.....	2
Potsherds, decorated.....	17
Antler fragments, worked.....	3
Antler dagger handle	1
Potsherd, salamander decoration in relief.....	1
Potsherd, broken.....	1
Potsherd, human face effigy	1
Pottery disks	2
Stone disk	1
Triangular arrowheads	4
Bone awl	1
Bone bead	1
Pot rim fragments	3
Fragment of pipe	1
Worked trilobite fossil	1
Fragment of worked antler	2

Potsherds	3
Worked shell	1
Nichols Pond, Oneida site, Fenner, Madison county	
Bone awls	2
Bone awl, polished and notched	1
Worked bones	2
Bone awls, short.....	8
Bone bead	1
Brass bead	1
Miscellaneous flints	8
Phalanx bones	3
Shuttle or needle, bone	1
"French" iron axe.....	1
Atwell site, Cazenovia	
Decorated potsherd	1
Pottery face	1
Pottery pipe fragment, showing many faces	1
Potsherd (handle or ear)	1
Dog teeth	3
Antler cone	1
Broken awls	3
Pipe stem fragments	2
Rude flint spear	1
Antler pitching tools	2
Notched net sinker	1
Antler tips, worked	3
Triangular flint points	2
Bear teeth	3
Pottery face.....	1
Bone awls, small	5
Bone spear, broken.....	1
Chisel, bone	1
Fragments, animal bone	2
Onondaga county, Pompey sites	
Trade beads, strings on card	8
Wells, Miss Lucy S. Naples	
Flat vase pipe, stone bowl	1
Pottery pipe bowl	1
Shell cylindrical bead	1
Runtce shell beads	2
Celt	1
Owl head effigy, clay	1
Jesuit rings	2
Catlinite ornaments	3
Catlinite face effigy	1
Shell, heron (?) effigy	1
Small celts	2
Arrowheads	6
Iron tomahawk blade	1
Sioux brush	1

Donation

Hine, Dr J. W. Albany	
Copper spear (should have been acknowledged last year)	1
Clarke, John M. , from Peter Barlow	
Mic-Mac relics, Bonaventure county, Province of Quebec	
Celt	1
Quartz arrowheads	2
Quartz knife	1
Wren, Christopher. Plymouth, Pa.	
From the Susquehanna river valley, between Pittston at the upper end of Wyoming valley and Sunbury (Shamokin) at the junction of the north and west branches	
Argillite arrow point found at Retreat (material from Delaware valley near Trenton)	1
Rhyolite arrow point, Hunlocks creek (material from quarry near Gettysburg, Pa.)	1
Ordinary arrow points, Hunlocks creek	5
Arrow points, Sunbury, Pa. (formerly Shamokin and the home of Shekillemy)	10
Piece soapstone pot, Hicks Ferry	1
Fine argillite celt, Beach Haven	1
Green rubbing stone, Dundee farm, Wyoming valley	1
Sinew or bow string dresser, Nanticoke, Pa.	1
Sinew or bow string, Buttonwood Flats	1
Sinew or bow string, Shawnee Flats	1
End notched net sinkers	3
Side notched net sinkers	4
4 notched net sinkers	1
Large chipped net sinkers, notched disks	2
Small chipped net sinkers, notched disks	2
Piece of red paint, Plymouth, Pa.	1
Small common pitted stone	1
Large double flat ended hammer stone, not grooved, West Nanticoke	1
Large pitted and notched hammer stone, flat ends, Shawnee Flats	1
Net sinker, grooved, thick	1
Common hammer stone, Nanticoke	1
Crude argillite hatchet, Wapwallopen	1
Common hammer stone, Shawnee Flats	1
Argillite axe not grooved, Dundee farm	1
Extra pitted stone, Shawnee Flats	2
Common chipped hatchet, Nanticoke	1
Small muller, Buttonwood Flats	1
Fine muller, Dundee farm	1
Metate, Shawnee Flats	1
Soapstone pot handle, Northumberland, Pa.	1

ETHNOLOGY

*Purchase and collection in the field***Parker, A. C.**

Carving of wolf head totem.....	I
Basket sieve	I
Corn meal sieve (basket).....	I
Bow and 2 arrows	3
Husking pin of bone.....	I
Turtle shell rattles	2
Baby board	I
Bowl, carved of wood	I
Bone whistle.....	I
Water drum	I
Snow snake	I
Dolls	2
Woman's cincture	I
Calabash rattle	I
Husk moccasins.....	4
Tortoise rattle	I
Bark rattle	I
Husks for weaving, bundle	I
Peach stone dice.....	8
Husk tray	I
Husk salt jugs	2
Husk masks	3
Death feast paddles	2
Ceremonial doll	I
Powder charger, bone	I
Crooked knife, antler handle.....	I
Medals, small	2
Corn hulling basket, low	I
Wooden bowl for holding bread	I
Wooden eating bowl	I
Child's eating bowl	I
Wooden spoons	2
Beaded skirt	I
Head band, Abenaki	I
Pack strap, fragment, Abenaki	I
Rolls of colored splints, Abenaki	3
Paddles carved	I
Leggins, women's, pair	I
Woodchuck skin for drum head	I

Burmaster, E. R.

Wooden spoon from bottom of Black lake	I
Buffalo horn spoon.....	I
Abenaki quilled robe.....	I
Abenaki ceremonial mats	3
Seneca woman's leggins, pair	I
Workbasket	I
Deer bone buttons, game	8

Peach stone dice, game	6
Tump line	1
Dried corn scoop	1
Salt jug of husk	1
Moccasins, pair	1
Bead workers outfit	1
String purple wampum	1
Neck bands	2
Evaporating tray	1
Sifting baskets	2
Spoons	2
Wooden bowl	1
Hominy ladle	1

Loan

Bush-Brown, Henry K. Newburgh	
Brooch and scalp lock	1
Turtle shell amulet	1
Moccasins, pair	1
Mountain goat quiver and bow	1

Donation

Bush-Brown, Henry K. Newburgh	
Set of old carpenters reamers.....	12

Purchase

Harrington, Prof. M. R.	
Iroquois specimens	
Baby board	1
Silver brooches	10
Melon baskets	2
Cherokee specimens	
Baskets	11
Ball player's sticks	2
Pottery vessels	2
Pottery effigy	1
Potters paddle	1
Potters stone smoother	1
Miniature (woman's) pipe	1
Moccasins, pair	1
Ceremonial scratcher	1
Schmidt, A. A.	
Decorated birch bark boxes	2

MISCELLANEOUS

Donation

Putnam, William R. Wayville	
Fork and hoe plowed up near Saratoga lake.....	2

X

THE NEW YORK STATE MUSEUM ASSOCIATION

In order to bring into more intimate touch with the State Museum the citizens who are disposed to appreciate its intentions and purposes, the Director has invited a considerable body of representative men from all parts of the State to participate in the organization of an association, which shall have for its purpose the intelligent support of this organization. The members of this association are entirely voluntary adherents from whom nothing is asked but a reasonable expenditure of public spirit and moral support. The work of the State Museum is very widely known in the scientific world, but in spite of its more than half century of existence, it is not so widely known among the citizens of the State as it ought to be. In consequence it suffers in educational effectiveness and in a general widespread touch with the scientific and intellectual interests of the public. The New York State Museum Association is designed to increase the usefulness of the institution by bringing its work nearer home to the citizens of the State. Invitations to enroll in the membership of this organization have been extended, not miscellaneously but to members of the community selected on the basis of demonstrated public spirit and civic usefulness in other directions. It is however greatly desired not to exclude from this enrolment the name of anyone to whom the activities of the State Museum make a direct appeal. Such names, even though not reached by the invitations sent out by the Director, will be welcome additions to the enrolment. All have been asked to remember that this museum is the only institution of the kind which the State has undertaken to maintain and should therefore in every respect be made creditable to the commonwealth and commensurable in influence and interest with similar institutions supported by private beneficence.

In undertaking this organization the Director invited several men of distinction to act with him and thereby to give the weight of their indorsement to this association. All thus invited cordially assented to act with the Director as a provisional executive committee, composed as follows:

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COMPARATIVE SKETCH OF THE PRECAMBRIC GEOLOGY OF SWEDEN AND NEW YORK

BY J. F. KEMP

The eleventh International Geological Congress, which was held in Stockholm, August 17 to 25, 1910, afforded visitors from elsewhere exceptional opportunities to become familiar with the Scandinavian Precambrian exposures and problems. One excursion of three weeks' duration, before the sessions of the Congress, was planned for northern Sweden; while a second covering ten days was devoted to southern Sweden. Besides these two, and both before and after the sessions, two others were tendered the visitors specially interested in the iron ore deposits. The mining trip before the Congress in part coincided with the one planned for the Archean geologists but the two that came afterward were essentially different. Since in each group was a member of the New York State Survey, Mr Newland accompanying the mining sections and the writer the Archean, it has been thought by these two observers that a sketch of the geology of the Swedish magnetites as compared with those in New York, and an outline of the Swedish Precambrian as compared with the home exposures would present elements of interest. The latter sketch may be best given first since all the iron ores are in the very ancient strata.

A few figures of relative areas will be of interest in establishing a point of view. New York contains 49,170 square miles, of which 1550, or about 3 per cent, are lakes. Sweden covers 172,876 square miles or approximately three and one-half times as much as New York; one-twelfth of its area consists of lakes. Norway has 124,445 square miles, so that Scandinavia proper is nearly six times as great as the Empire State. Were we to take together with New York the New England States, Pennsylvania and Maryland, the total would be very nearly that of Sweden. Sweden, however, is so much narrower that if we lay it off from the northern point of Maine, it would reach a little beyond the extreme southern point of North Carolina. In population of the date 1900, Sweden had 5,136,000, and Norway, 2,240,000. The total of the two was a little more than New York's 7,268,894. In 1910 New York had grown to 9,113,279, but the two Scandinavian countries have probably not

changed so much. The Precambrian rocks in New York cover about 11,800 square miles, or about one-fourth of the dry land. In Sweden the proportion is far larger, perhaps nearly nine-tenths. Since one-twelfth of Sweden is covered by lakes the areas compared are therefore nearly in the ratio of 4 to 50.

The older Paleozoic section in Sweden is not so thick as in New York, yet its exposures are very widespread. The relicts left by erosion and spread as they are in scattered areas throughout the kingdom, indicate the very general presence of these strata at one time over all of its extent. The island of Gothland in the Baltic and the many glacial boulders of the older Paleozoic rocks, which are found in the drift in the Åland Islands, Finland, lead to the belief that other areas are beneath the waters of this inland sea. The lower members of the Paleozoic are grouped under the name Siluric which is then subdivided in descending order into Gothlandic, Ordovician, and Cambrian. The Swedish geologists thus follow the lead of Murchison. We are here chiefly concerned with the contact of the Cambrian upon the ancient crystallines. This is of such a character as to prove the old bedrock upon which the first Cambrian strata were deposited to have been in general very even. Such relief as can be detected in most of the areas is slight and the old land surface seems to have been worn nearly to a level.

These observations coincide with the greater part of the observations around the Adirondacks. Professor Cushing has demonstrated the very even sub-Potsdam floor along the north and northwest sides (1)¹ and has recently discovered in the southeastern edge much the same relief, although hummocks as high as 100 feet seem recognizable. Doctor Ruedemann has described in some detail the small inliers of gneiss amid the encircling Potsdam at Port Henry. (2) In the quadrangles mapped by Prof. W. J. Miller along the southwestern edge, the same condition is indicated but, as is well known, sedimentary overlap brings several of the Ordovician members in contact with the Archean. The escarpment of the Medina sandstone in the Little Falls quadrangle led Professor Cushing to strongly suspect that it, too, had once extended over the ancient gneisses (3).

The writer has suggested the original extension of the Ordovician and Cambrian sea up valleys in the Archean along the eastern side

¹ The figures in parentheses refer to the bibliography at the close of this paper.

of the Adirondacks at the time of deposition. There is some ground for this inference. Similarly in the actual highlands of Sweden, land areas, already carved into hills and deep valleys, are believed to have existed in Cambrian time (4, p. 6).

The nature of the surface on which the Poughquag sandstone north of the Highlands of the Hudson was deposited is so little exposed that we can cite it for comparison.

Professor Högbom states (4, p. 4) that at most of the contacts between the Cambrian and older rocks in Sweden, one finds the bottom layers of the former resting on a weathered breccia of the subjacent Archean. The breccia turns into kaolinized gneiss which continues to a depth of one or two meters. These relations are paralleled at the "Noses" along the Mohawk where the Beekmantown limestone rests on decomposed gneiss (5) but the general experience in New York is to find rather fresh Precambrian rocks beneath the Cambrian, as if the advancing waves had swept the old bedrock clean of the products of weathering. In Sweden one curious feature of these contacts remains far away from present exposures of the Cambrian strata. A few little, so-called "sandstone dikes" have been found in crevices of the ancient gneisses. In them Cambrian brachiopods which serve to establish the age have been detected. One of these on a high hill of gneiss, on an island off the east coast of southern Sweden, not far from Västervik, was shown to us and excited much interest. It reminded the Americans of the similar explanation suggested by Prof. J. E. Wolff for the narrow Cambrian quartzite in the crystalline limestone at Franklin Furnace, N. J., (6) discovered by Mr F. L. Nason and believed by him to be interbedded (7).

The most recent scheme of classification of the Precambrian which has found favor in Sweden is in part the one suggested by Professor Sederholm, the Director of the Geological Survey of Finland, where, over a vast area, scarcely any other than Precambrian rocks appear, and where careful studies have been carried on in later years. In part also it has been suggested by Professor Högbom of Upsala. Beneath the Cambrian strata we find the following (4, p. 2):

	}	Epijotnian dislocations
Upper or Jotnian		Jotnian
		Subjotnian land surface denudation and igneous rocks

Middle or Jatulian	{ <i>Jatulian</i> }	Epijatulian folding
		Subjatulian land surface and denudation
Lower or Archean		{ <i>Archean</i> }	Serarchean granites
	No chronological subdivision. Differences due to varying metamorphism	

Along the more northerly border of Sweden and Norway there is a great development of moderately metamorphosed sediments and of less evident gneisses which have been called the Seve series. Professor Törnebohm has shown that they rest upon the typical Jotnian sandstones and considers them a later formation. Professor Högbom is inclined to place them in the Jotnian as an upper division. Their great point of interest lies in the fact that they have been thrust-faulted upon the Cambric and Ordovician fossiliferous beds and thus appear above strata which are later. They have ridden in from Norway, and when one looks for the parent exposures the latter are now 100 to 150 kilometers distant. The thrusts, therefore, if existent are greater than any yet described elsewhere. On the other hand some Swedish geologists oppose the explanation by thrust faults, and insist that there is a regular stratified series. They are then confronted with the difficult problem of higher lying and strongly metamorphosed and rather flat strata resting upon others scarcely if at all metamorphosed and at times richly fossiliferous.

We visited several crucial localities in Jämtland where we could locate the fault plane within narrow limits although it was not itself visible, but on Mt Luopahta in Lapland we saw it clearly beneath a small waterfall. Black and greatly crushed Lower Paleozoic slates supported a heavy stratum of so extremely crushed and disguised a member of the Seve series that an earlier Swedish geologist had given the rock the special name "kakirite," from Lake Kakir in Lapland. In Jämtland the rocks are collectively called "sparagmite" from the Greek word meaning to crush.

With the typical or lower Jotnian we have no equivalent in New York. It is a series of sandstones and diabases much like the Torridonian of Scotland and the Keweenawan of the Lake Superior region and Canada. In Sweden it appears in scattered areas much

as do the Cambro-Siluric strata. The largest area is in middle Sweden along the boundary with Norway. The Jotnian sandstones exhibit perfectly preserved sun-cracks and ripple-marks and may display but little in the way of metamorphism.

The sandstones and diabases along the beautiful coast of eastern central Sweden in the district of Nordingra were shown to the visiting geologists. The sedimentary characters were as well preserved as in our Siluric Medina sandstone, as for instance at Lockport, and the grade of metamorphism was scarcely greater. This recent aspect led earlier observers to correlate the sandstones with Paleozoic formations, notably the Old Red Sandstone, but the Precambrian age is now very well established (4, p. 10-11).

The floor of older rocks beneath the Jotnian is very even so far as visible and reminds one of the floor beneath the Cambrian. The foundation rocks are, however, devoid of products of weathering and seem to have been swept clean by the oncoming waters. The Jotnian sandstones, sometimes many hundred meters thick, far surpass the Swedish Cambrian, and since the quartz grains in them were probably freed by the weathering of older rocks the sub-Jotnian time interval is believed to be far greater than the sub-Cambrian.

One extraordinary feature of the eruptives is the curious "Pebble diabases" near Brevik, in central southern Sweden. Dikes of diabase are so fully charged with rounded boulders, that the observer can only interpret them as follows: it appears that a loosely compacted conglomerate, or even a boulder bed, has been penetrated and suffused with a basaltic magma as with so much water; on chilling, the result was a rock almost like a conglomerate, with a basalt bond or cement. We have few parallels for these rocks in America, but one is reminded of a dike at Nash's Point, Vermont, where a trachytic magma is surcharged with boulders derived from lower lying formations, although it now cuts Ordovician slates (8).

In the table of formations given above, under Jotnian is mentioned a group of sub-Jotnian igneous rocks. A brief outline of these will serve also to explain the methods of correlation developed by the Swedish and Finnish geologists when dealing with igneous and metamorphic rocks in disconnected areas. The Jatulian period closed with strong folding, as will be later brought out. Subsequent to the folding there appeared in Finland extensive intrusive masses of a peculiar granite, of coarse porphyritic texture. The porphyritic crystals may be one to two inches

in diameter. They have a core of reddish orthoclase and a rim of green oligoclase and are very characteristic. The granite weathers badly and for this reason has received the Finnish name rapakivi or rotten stone. Wherever these porphyritic granites or even finer-grained porphyritic rocks are found with the zonal phenocrysts, they are called throughout Scandinavia rapakivi.

Now, the Finnish rapakivi is later than the post-Jatulian folding. The rapakivi can be traced across the Åland group of islands which separate the Baltic sea from the Gulf of Bothnia and themselves have rapakivi rocks. It finds parallels or representatives farther north along the east coast of middle Sweden near Sundsvall, and inland about 60 miles at Ragunda. In this latter region the granitic rocks of coarse texture lie beneath the Jotnian; but their texture shows that they crystallized beneath a load which was eroded before the Jotnian sandstone was deposited. Thus we have a long time interval between the close of the Jatulian period and the beginning of Jotnian sedimentation. If now we establish the geological date of the Swedish rapakivi, near Sundsvall, we also fix the time of various other types of igneous rocks, such as diabases, gabbros and granites, which cut the rapakivi but precede the Jotnian sandstone. Extremely interesting exposures of all these were shown to the visiting geologists at and near Ragunda, Sundsvall and north along the coast in Nordingra, and are described in the guidebooks to Excursion A 2. The visitors viewed with growing enthusiasm the impressive phenomena of interrelated igneous types which Professor Högbom spread before us, nor will we ever forget the deep impression made by them.

The most extensive of the Jotnian exposures, as stated above, lies in western middle Sweden along the Norwegian boundary. The underlying rock consists largely of the famous Dala-porphyrries, which are a subject of much difference of opinion. Some think them Archean; others are not convinced that this is true and urge a later age.

Near Sundsvall, which is a city in eastern central Sweden, and the most important lumber center of the country, there is the island of Alnö, with its famous nephelite rocks, whose age is uncertain. In many places throughout Sweden there are diabase dikes whose age is also indefinite. It is conceivable that they may belong in this interval between the Jotnian and Jatulian.

New York can not furnish parallels for all the formations just reviewed. As earlier stated, the Jotnian seems nearest akin to the

Keweenaw of the Lake Superior region; but if, with Professor Högbom, the Seve group is considered upper Jotnian it might furnish a parallel with the Manhattan schist and Inwood limestone of southeastern New York. At all events the Seve group as represented by the Åre schists is lithologically very similar to the latter. The Grenville on the other hand is much more like the sedimentary rocks in the Archean, than like the Jatulian.

As a parallel with the Dala-porphyrries we have the Precambric volcanic rocks which are so generally distributed along the Atlantic seaboard (9); which have been well described in Wisconsin (10); and which are of special interest in southeastern Missouri (11). We can only say that porphyritic and felsitic rocks were also developed on this side of the ocean.

The Jatulian (pronounced Yatulian) series was named originally by Professor Sederholm of Finland. The exposures which primarily suggested its establishment are found in the latter country. They consist of quartzites, schists, dolomitic limestones and, strange to tell, of beds of anthracitic carbon, which may attain a thickness of two meters (12, p. 10). Strata referable to the Jatulian are less abundant in Sweden and are in fact practically limited to one area, the west side of Lake Wenern in the southwestern portion of the country. They constitute a series of folded and metamorphosed sediments, long known as the Dal-formation.

The sub-Jatulian surface, or the one beneath the Dal-formation, is believed by Professor Törnebohm to have been a mountainous one, with valleys cut quite deeply, but Professor Högbom considers it to have been at most hilly. There is thus a time-gap represented by erosion, but not of so great length as either the sub-Jotnian or sub-Cambric.

Back of the Jatulian lies the vast complex of extremely difficult rocks forming the Archean of the later Swedish geologists. The term is not used by them exactly in either the original sense of Precambric as given by Professor Dana, nor the later modification to which it has been subjected by the Lake Superior group of geologists, as embracing only those rocks which were older than recognizable sediments; but it applies to the great complex of ancient rocks, consisting either of deep-seated intrusives or of sediments always heavily metamorphosed. On the bases of the characters shown by the foundation rocks on which the Jatulian rests, Professor Högbom infers an erosion of some thousands of meters and therefore the greatest time-break in the history of the earth.

Undoubtedly the obscurity which always surrounds the products of deep-seated processes has in large part served to make the interpretation of these rocks difficult. The tendency of earlier geologists to see in the gneissoid structure evidence of sedimentary bedding has also stood in the way of conceptions characteristic of later workers.

In outlining the Swedish Archean we may establish therefore at the outset that,

1 It closed with a vast period of denudation.

2 Back of this there was a very important development of granites which may be classed under four types.

3 Back of the granites just referred to there is a great complex of minor sediments and major deep-seated intrusives.

To the time interval of erosion, reference has already been made. The granites are widespread and of great interest. They are characteristically massive. While Professor Högbom makes four types, Professor Törnebohm, on the map of the Swedish Geological Survey, distinguishes three groups, each with several subdivisions. The four types of Professor Högbom embrace (*a*) a coarse-grained gray or reddish porphyritic granite, one of whose occurrences is called the "Refsund" and was seen by the foreign visitors. It is difficult to mention any familiar American occurrence that is closely similar. (*b*) A fine to medium-grained gray or light reddish biotite granite which is prominent in the city of Stockholm itself where it was shown to the members of the Congress. The quarries in Stockholm remind a visitor of Dix Island, Maine; Barre, Vt.; and Westerly, R. I. (*c*) A true muscovite-granite in Ångermanland which was not in the routes of the excursions. (*d*) Coarse pegmatitic granite which we saw on the island of Utö. All of these types are grouped by Professor Högbom under the name Serarcean or late Archean, a rather bad word etymologically, as it has a Latin prefix (*serus*, late) to a Greek derivative, Archean.

The members of the great complex, older than the granites just mentioned, present an extremely difficult subject to set forth intelligibly in a short space or even for a Swedish geologist of a lifetime's experience to make comprehensible. We may select, however, certain main features.

Sedimentary rocks are represented by the usual types. There are greatly compressed conglomerates, one of which was shown to us near Malmbäck in southern Sweden. The pebbles of finely crystalline rocks were pinched out to lenses and, while easily recog-

nizable, were well on their way toward gneisses. The rolling out and flattening produced by the great pressure were very impressive. We have no parallels in New York but in the Lake Superior region similar phenomena may be seen.

Quartzites are at times well preserved, and while hard and dense and obviously the results of extreme metamorphism, they are typical cases of the rock. In the city of Västervik they were shown to the visitors in excellent exposures.

Crystalline limestones and dolomites are important members. They appear in the mining districts of southern Sweden and are at times the wall rocks of important ore-bodies, as at Sala. The excursionists saw them in a number of localities.

Mica schists are also frequent rocks. They are associated with the group of leptites.

Leptite is a comprehensive name now largely used for the fine-grained and banded or stratified rocks which are of great areal extent in middle and southern Sweden and which, with the associated sediments just cited, contain the ore bodies. Leptite, derived from the Greek word for fine-grained, is not a name of a special rock but of a group whose grain or texture is very small. The varieties cover a wide range and have doubtless resulted from several different original rocks. The hälleflintes of the early writers are included. They are flinty-looking rocks which consist of minute quartzes and feldspars and are well known in the iron-mining regions. Many more coarsely crystalline varieties than the excessively fine hälleflintes are also included under the term leptite, although their grain is always minute. Generally speaking, the leptites remind one of the Saxon granulites more than anything elsewhere. They may be sheared and crushed effusives. They may be consolidated and metamorphosed tuffs. They may be sediments recrystallized to rocks of minute grain. Somewhat similar types can be recalled in a few cases in America, but they are not common. We have none in New York.

Gneisses with garnet, cordierite, sillimanite and graphite are not unimportant members of the great complex. They are believed to be of sedimentary origin. They remind one strongly of some of the gneisses of the Grenville series in the Adirondacks. Exposures of the so-called "garnet-gneiss" a few miles east of Stockholm at Fagersjö, which were reminiscent of some of the Adirondack rocks, were shown to us. Though long regarded as sedimentary by the Swedish geologists, there is now a decided disposition to consider

the "garnet-gneiss" as a complex mixture of igneous intrusives and partly digested sediments. It contains remarkable angular masses of amphibolite which seem to be torn off rather by a deep-seated igneous mass than by mechanical flowage.

A very important member of the complex is the time-honored "iron-gneiss," a rock of granitic composition with grains of magnetite distributed through it, but never segregated in amount rich enough to be of economic value. It is prominent in southern Sweden and is believed to represent a granite magma whose differentiation was so diffuse as never to have yielded an ore-body. The particles of magnetite are rather more prominent than in any of our ancient granitic gneisses other than such as the lean ores at Lyon Mountain and at the Benson mines. Geologically, however, the parallel is close.

Breaking through the sediments and the leptites are, furthermore, great intrusive masses of granite with gneissoid foliation, concentric with the borders of the batholiths and with massive textures at the center. When mapped in some of the areas, the sediments and leptites look like relatively narrow channels amid an archipelago of large islands of the intrusives. In these channellike belts are found the iron ores of southern Sweden.

Along the southwestern border with Norway, very coarse granitic gneisses appear, strongly banded and sometimes with streaks of amphibolite. They have "eyes" of feldspar an inch or more in diameter, and very strongly remind the American visitor of some of our old Laurentian gneisses. They were shown to us near Trollhätten.

Another feature of the Swedish Archean that is of especial interest to the visitor familiar with Adirondack geology is found in a series of basic intrusive masses which run north and south through southern central Sweden and which swing westward as they pass north and reach the Norwegian boundary. They are called hyperites and are later than certain quartzites of the region. The rocks are practically the same as the basic gabbros of the Adirondacks and, like them, contain bodies of titaniferous ore. The most famous of the latter, Taberg, was shown to the visitors. Its geology is practically the same as the many bodies known to us in Westport and Elizabethtown, but Taberg is much larger than any of ours.

Anorthosites appear in Sweden just as they do in the Adirondacks and in the province of Quebec, but not on so extensive a scale as in America. Exposures were shown to us on the north-

eastern coast in the district of Nordingra that reminded the writer very strongly of the American rocks. In Norway both the anorthosites and basic gabbros appear and with them are the syenitic series of the New York geologists (mangerites of the Norwegian observers) as Professor Cushing made clear some years ago (13).

Along the southeastern coast of Sweden between Stockholm and Västervik the visitors were shown phenomena that were new to the greater number of us. Innumerable islands dot the coast; they have been smoothed and polished by the great ice sheet until over widths of 10 to 20 yards along the shore the ledges appear as if prepared by a lapidary. Two rock magmas, a gabbro and a granite, are intermingled in the most intimate way. In the ledges visited by us, the granite had habitually pierced the gabbro, but in less accessible localities we were told that the relations are reversed. The granite at times seemed fairly to impregnate the gabbro with its red orthoclase crystals and to half digest it, until the observer hardly knew which rock name would apply. In another locality, Trollholmen, we saw contacts of gabbro on quartzite with similar absorption phenomena, leading at times to quartz-bearing gabbros.

When the interpenetration of two deep-seated magmas becomes very intimate and pressure phenomena or marked flowage later produce gneissoid structure, peculiar "veined" or "injected" gneisses may result. Finland also furnishes very instructive exhibitions of these phenomena which were described to us by Professor Sederholm. In fact the members of the Congress who saw the exposures and took part in the discussions based thereon, became deeply impressed with the importance of always keeping in mind the possible deep-seated conditions which have produced the phenomena and of adjusting explanations in accordance with them.

One extremely striking case of what is considered differentiation was the object of a day's study on the island of Ornö, just off the coast, east of Stockholm. A central, coarsely crystalline mass of diorite is surrounded by a border of finely but persistently banded, differentiation products. The latter appear as light and dark bands, respectively feldspathic (salic) and amphibolic, pyroxenic or biotitic.

The bands vary from a fraction of an inch to several inches in width and with slight variation may run for hundreds of feet. They are concentric with the diorite. They remind one of some cases of persistent foliation in our old gneisses, such as the Ford-

ham, but the writer had never seen anything of equal perfection. Our ancient gneisses are more coarsely crystalline. Ornö is well illustrated in reference (14).

In the far north at the two iron-mining districts of Gellivare and Kiruna we saw geological sections in some respects different from anything mentioned above. At Gellivare, syenitic rocks are the ones associated with the ore bodies and strongly remind one of the walls at Mineville, and elsewhere in the Adirondacks. At Kiruna we find an extended section from syenites below on the west, through two thick sheets of porphyry, with the ore-sheet between them, to a series of sediments and schists of various sorts which constitute the eastern section and which remind one both of the Huronian and the Keewatin strata of the Lake Superior region.

With the above general review of the component rocks in mind, we may grasp some of the larger features of the Swedish Archean. The sedimentary rocks and the leptites appear in separated localities. It is necessary therefore to treat them individually, just as our New York geologists have of necessity first studied the Adirondacks and the Highlands of the Hudson as distinct areas, and the Lake Superior geologists have taken up one by one the several iron ranges. Parallels may then be later drawn and correlations may be established. The correlations are, however, necessarily based on lithologic characters and on the parallelism of great unconformities or periods of faulting. The igneous masses must in time be matched by their lithologic characters and mutual relations. It would lead to too long and involved a discussion were we to attempt in this paper to follow out the several areas. They must be studied in the Swedish monographs and with maps in hand. In this way, however, the correlations have been elaborated. All Scandinavian geologists are not agreed upon the parallels which have been suggested. It is easy to see, however, that in the nature of the case these equivalents are largely matters of opinion rather than the results of demonstration.

The ordinary metamorphosed sediments of Sweden have many close parallels in our Grenville strata, but the leptites are not known with us. The granites, syenites, hyperites and anorthosites are much the same on both sides of the ocean, but the peculiar rapakivi type fails here. In New York and in the East in general, the writer knows of no such remarkable interpenetration phenomena as those seen in Sweden, but the Lake Superior region may contain them. Notwithstanding the contrasts, there remained in our

minds a profound impression of similarity and resemblance, so much so, that while in the field the Americans in the end became embarrassed at their constant and almost irrepressible tendency to remark upon it to their Swedish hosts. The visitors were fearful lest they prove wearisome.

In conclusion the writer may express his indebtedness to Professors Högbom, Holmquist and Bäckström and to Doctors Quensel and Gavelin for the personal guidance and explanations which made the excursions so exceptionally instructive.

As an appendix to the remarks on Swedish geology, a brief statement of the scheme of classification adopted by Professor Sederholm in Finland may be given. As will appear, the older rocks have been more extensively subdivided in Finland than in Sweden. The American equivalents suggested by Professor Sederholm are added.

Jotnian	Diabases, labradorites and clastics, rapakivi granites	Keweenawan
	Unconformity	
Upper Jatulian	Eruptives, clastics, anthracite, dolomite	Upper Huronian
Lower	Greenstones, clastics, dolomites Unconformity. Post-Kalevian granites	
Upper Kalevian	Greenstones, clastics Unconformity	Lower Huronian
Lower	Greenstones, schists, clastics, dolomites Unconformity. Post-Bottnian granites	
Bottnian	Eruptives, clastics, leptites Unconformity. Post-Ladogian granites	
Ladogian	Greenstones, phyllites, schists, clastics, limestones, hälleflintes	
Katarchean	Granitic gneisses, greenstones etc.	

In the above table I have condensed the rock types under collective names, like clastics, and have called by the name greenstone, rocks described by Professor Sederholm as metabasites. The full table, printed in English, will be found on page 93, Bulletin 23, of the Geological Commission of Finland, 1907.

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The writer has drawn especially upon this paper. It presents in English an excellent résumé.
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The paper gives excellent views of these wonderful exposures.

In addition to the references to the Swedish literature specifically referred to above, the writer has also used a pamphlet by Prof. A. E. Törnebohm, Explanatory Remarks, to accompany the Geological General Map of Sweden. This map, on a scale of 1 : 1,500,000, or about 25 miles to the inch, has also been used. A much larger one has been issued by the Swedish Survey. The members of the excursions in connection with the Congress were furnished with excellent guidebooks. The writer has especially drawn upon nos. 1-6, 15 and 18.

NOTES ON THE GEOLOGY OF THE SWEDISH MAGNETITES

BY D. H. NEWLAND

The general features of the Precambrian geology of Sweden are outlined in the paper by Prof. J. F. Kemp which should be consulted in connection with the following notes on some of the Swedish districts notable for their magnetite deposits. Inasmuch as these ores have likewise an important place in the mining activity of our own State and much uncertainty surrounds the relationships and origin of the local deposits, it is thought that a brief discussion comparing the two series of occurrences, though so far removed from each other, may well be presented here. The notes are based on observations of the writer while a participant in the excursions of the International Geological Congress during the months of August and September 1910. The excellent guides to the different mines, prepared by the Swedish geologists for the use of the visiting members, have been freely consulted for details, as have also some of the reports and monographs from other sources.

The iron industry of Sweden, as is well known, derives its raw material from magnetite deposits in the Precambrian rocks. In this respect the country stands practically by itself among the more important iron producers of Europe; for elsewhere the ores chiefly represented are hematite and limonite, or occasionally carbonate, associated with rocks of much later age. The magnetites are contained in crystalline schists and certain igneous rocks of acid composition that are all assigned to the Precambrian, though they may belong to widely variant horizons of the series. It is upon these ores and their features of occurrence, suggestive in some instances of the magnetites found within the Adirondack and Hudson River gneisses, that attention will be fixed.

Sweden also possesses deposits of titaniferous magnetites, quite analogous to those occurring in the Adirondack gabbro-anorthosite areas. One occurrence at Taberg, in southern Sweden, is of large size and has been mined to some extent in the past, but it is low grade, resembling in composition rather the magnetite-silicate mixtures of the smaller gabbro intrusions than the larger Adirondack deposits like those of Lake Sanford. There are many occurrences

of titaniferous ores among the igneous areas of southern Norway, and one of considerable magnitude at Routivara in Swedish Lapland.

A third group of ores which may be mentioned to complete the list, consists of the lake and bog limonites so frequently cited in the literature of ore deposits as instructive examples of present-day processes in ore formation. They are said to have furnished the first material for iron manufacture in Sweden. With the improvement of methods for working and treating the magnetites, the lake deposits have lost their importance and are no longer employed in the furnace.

While it is purposed to give particular attention to the geological features of the magnetites, some information on the industrial side will be useful perhaps for comparison with the present situation of iron mining in this country.

Of the two main districts in which the magnetites are distributed, central Sweden has long been and still is the support of the Swedish metallurgical industry. The deposits of that district are characteristically low in phosphorus and sulfur and the mine output is consumed locally in the manufacture of charcoal iron for which a wide demand still exists in spite of the development of methods for refining the ordinary product of coke furnaces. Mining there may be said to enjoy certain advantages that are not apparent in this country. The greater value of the ores as compared with those of usual composition admits their profitable extraction from small deposits and the expenditure of more labor in their preparation for the furnace than is economically practicable elsewhere. In the work "The Iron Resources of the World," recently issued by a committee of the Stockholm Congress, F. R. Tegengren places the number of active mines in central Sweden in 1908 at 277 and the total production of ore for the same year at 1,884,451 metric tons. In the total are included 262,620 tons of concentrates from 23 plants. When it is considered that about one-half of the product consisted really of high phosphorus ore, contributed by the Grängesberg and one or two other mines which are exceptional to the district, it is seen that the individual workings are very small. Such operations recall to mind the days of the forge iron industry in this State, when the numerous small deposits of the Adirondacks were actively worked with an individual output perhaps of a few hundreds or thousands of tons a year.

Some of the mines of central Sweden have been worked almost

continuously for the last four or five centuries. It is not to be inferred, however, that the methods and equipment at the smaller properties are, as a rule, crude or antiquated; on the other hand, they are often very efficient and the cost of production is surprisingly low on the basis of output.

The low phosphorus magnetites have no counterpart with us. They carry generally but a few thousandths or at most hundredths of a per cent of phosphorus and usually correspondingly low amounts of sulfur.

The deposits with moderate to high phosphorus content, which furnish the closest parallels to our own from a commercial viewpoint, have become prominent producers only in recent years when the export demand began to develop. The output of Grängesberg and the Lapland mines goes almost entirely to other countries, owing to the fact that Sweden has no coal suitable for blast furnace use. Since the completion of the Luleå-Narvik Railroad in 1902, by which the Lapland mines secured outlets to both the Baltic and the Atlantic coasts of Scandinavia, the shipments have grown very rapidly. This district now produces much more than central Sweden, the output for 1908 amounting to 2,724,886 metric tons, with a probable total around 3,500,000 tons for the current year. The shipments go to Germany, France, England and even to the United States, competing here with our own magnetic ores of the East.

The facilities for extraction and handling the product in the mines of Lapland are on the largest scale, as perforce they must be to permit exportation of a low-priced material like iron ore. Open quarry work is generally practised, though at Gellivare, where the pits have already attained considerable depths, underground mining is being introduced. The aspect of enterprise and permanency which the mines and their surroundings reflect is most pleasing, as it is rare enough in mining settlements under more propitious climates. Kiruna and Gellivare are flourishing towns of 6000 or 7000 inhabitants each, with attractive buildings and all the conveniences of modern communities, though both lie within the Arctic Circle.

The exploitation of the high phosphorous magnetites will probably not proceed as rapidly in the future as the mining situation might admit, owing to the strong position taken by the government in favor of their conservation in the hope that ultimately they will be used at home. A definite limitation has been put

upon the amount that can be exported; in the case of the Kiruna mines this is fixed substantially at 3,000,000 tons and for the Gellivare mines at about 800,000 tons annually during a period of 25 years. It is believed, however, that these amounts will be increased before long, as the magnitude of the resources becomes better appreciated. The possibility that the ores may be needed for iron manufacture in Sweden arises from the large water powers of the country and their future application to electro-metallurgy.

Turning now to the geological features of the magnetites, the Lapland deposits will be first considered for the reason that they have been on the whole less influenced by metamorphism, therefore are more readily interpreted, and their associations perhaps more nearly approach those found in some localities of our own State. Attention can be given only to the Kiruna and Gellivare mines since the limited time of the excursion did not permit any visits to the localities remote from the railroad.

Rocks of syenitic composition are the prevailing ones associated with the magnetites of Lapland. They range from massive, even-textured or porphyritic, clearly igneous types to gneissoid and finely granular phases that have entirely lost their igneous structures. Quartz is a variable component. Magnetite, diopside, hornblende and biotite are the chief dark constituents. Areas of granite and gabbro interrupt the syenites, and the latter are penetrated by dike intrusions of pegmatite, granite and more basic rocks.

At Gellivare we saw the syenite in its varied development from massive to extremely granulated and gneissoid types. With the exception of local granite intrusions and certain small belts of a basic schistose rock that are considered by Professor Högbon to represent igneous dikes, the syenite prevails throughout the ore-bearing districts. No sedimentary gneisses are recognized in the vicinity. The general impression gained from the cursory field study and later comparison of the country rocks indicates close resemblance to the ore-bearing syenitic gneisses in the northern Adirondacks, particularly Lyon mountain, Palmer hill and Arnold. The main element of difference that can be readily pointed out is that in the Adirondacks the gneiss belts are seldom without some interfolded remnants of the Grenville sedimentary rocks. Mineralogically and chemically the two series are very similar. Both are characterized by high soda percentages, which place them in the soda-syenite class, the prevalence of perthitic and acid plagioclase feldspars, and by relatively large amounts of free iron oxid in the form of mag-

netite, which has, however, a very unequal distribution due to its tendency to aggregate in bands and schlieren surrounded by rock containing less than the average proportion of magnetite.

The Gellivare iron ores occur in the form of lenses, bands and chimneylike bodies with a linear arrangement that conforms more or less closely to the secondary structures of the wall rocks. Three or four parallel series of deposits can be recognized, the individual members of which vary in magnitude and shape and also in their characters. There is the same tendency toward overlapping which is so pronounced in most of the Adirondack mines. Horseshoes of pegmatite and of the country rock are not infrequently encountered in the midst of the ore, reminding one of the occurrences in the "Old Bed" mines at Mineville and in the Lyon mountain deposits. The similarity of the two districts has been noted by Professor Sjögren who visited Mineville in 1891.¹

The ores themselves present some striking contrasts. The high phosphorus ores are the same granular mixtures of magnetite and apatite as are represented by the product of certain Adirondack mines, but on the other hand the mixed magnetite and hematite ores and the purer bodies of the latter in contact with, or independent of, the magnetite are foreign to our State. This feature we found to be repeated at Kiruna and in many of the central Sweden localities. The hematite is specular and not pseudomorphic after magnetite as is the case with the few occurrences of this mineral in the Adirondacks. Here it is undoubtedly a result of catamorphic processes in very limited areas in which the magnetites have been intruded, faulted or otherwise exposed to accentuated weathering. Professor Högbom² refers to the possible secondary origin of the hematite at Gellivare, stating that this derivation is suggested at times by decomposition of the adjacent wall rocks; but he also points out that the contacts cannot be distinguished in other cases from the magnetite contacts. The relation of the two ores in this district is thus open to question. With reference to Kiruna, Dr Per Geijer³ expresses the view that the hematite, except where its presence can be attributed to surface alteration, is an original constituent of the ore bodies, though in that section it appears to occur

¹ The Geological Relations of the Scandinavian Iron Ores. Am. Inst. Min. Eng. Trans. 1908, 38:794-95.

² The Gellivare Iron Mountain. Guide to Excursions of the International Geological Congress.

³ Geology of the Kiruna District. Stockholm, 1910, p. 257.

more commonly as veins which are regarded as having a somewhat different origin than the magnetites.

Kiruna with its three great ore zones, Kiirunavaara, Luossovaara and Tuolluvaara, easily ranks first among the Swedish magnetite districts. To Kiirunavaara must be conceded the credit also of being the largest accumulation of this ore of which we have any certain knowledge. The single deposit is estimated to contain more than one-half of the total available ore in Sweden, which is figured at 1158 millions of tons and recent magnetometric surveys indicate a greater extension of the mass than had been previously taken into account.

The three ore zones referred to outcrop on the summits of as many ridges which rise rather prominently above the Lapland plateau. The Kiirunavaara deposit is a continuous tabular or sheetlike mass forming practically the whole ridge of that name, which extends 3.5 kilometers north and south, and running under the lower ground at each end so as to give a total length of more than 5 kilometers. Its thickness ranges from a maximum of 164 meters to 50 meters or somewhat less, the higher points of the ridge showing the greatest width of ore. It inclines at a rather high angle to the east, disappearing under a mass of quartz porphyry.

The ore occurrence at first sight seems in strong contrast with the Gellivare type. The wall rocks are massive, porphyritic, and show little or no effects of metamorphic influences. Their structures are rather those of dikes or volcanic rocks than of intrusives which have crystallized by slow cooling at great depths. But the more striking features relate to the ore itself, which has a dense steely appearance, revealing no granularity or crystalline texture to the unaided eye and breaking with smooth surfaces like basalt; the ore furthermore is practically pure magnetite, the whole mass averaging about 96 or 98 per cent of that mineral, with apatite as the only nonmetallic ingredient of importance. Analyses sometimes run over 70 per cent in iron. The distribution of the apatite is very irregular, so that it has been found possible to extract in a large way several different commercial grades of ore from the one deposit. The interesting structures which develop out of the variable relations between the magnetite and apatite have been described by Dr. O. Stutzer¹ and more fully by Doctor Geijer².

¹ The Geology and Origin of the Lapland Iron Ores. Jour. Iron & Steel Inst. II. 1907.

² Geology of the Kiruna District. p. 88 et seq.

The Kiruna deposits were undoubtedly the most instructive in regard to considerations of ore-genesis that we saw in Sweden. There were few members of the excursion, apparently, who were not impressed by the evidences in favor of the igneous derivation of the magnetites, however much individual opinion may have varied in regard to the exact process by which the ore came to occupy its present position. The undoubtedly igneous character of the wall rocks, the structures exhibited by the ore itself, the dikes of apatite connected with the same and found in the porphyry, and the apophyses of ore in the footwall of Kiirunavaara and more notably in the surrounding porphyry of Tuolluvaara, seemed conclusive on that score. These features have been admirably set forth in the monograph by Doctor Geijer already quoted, and further discussion of them here may be spared.

As to the precise construction to be placed upon the evidences, for a theoretical explanation of the ore genesis, the views of the Swedish geologists and others who have studied the district are somewhat at variance, though many accord on the more essential points. Högbom, Sjögren, Stutzer and Geijer agree that the magnetites have been derived from the porphyries and that their concentration primarily has been due to magnetic differentiation. But these authorities take issue on the problems connected with the subsequent history of the ores for which it is possible to give several versions: the magnetites may have cooled in place along with the wall rocks; again, they may have been forced up through the partially or completely cooled rocks in the form of dikes like those of pegmatite; or they may have flowed out on the surface as lava sheets in an interval between the eruption of the foot-wall and hanging-wall porphyries. Of course the different views do not conflict with the validity of the general principle, and it is not improbable that the sequence of events with respect to the several deposits may be explainable in more than one way.

The relations of the Kiirunavaara-Luossovaara ores seem exceptional in that the two walls have a somewhat different composition—the hanging being classed as a quartz porphyry and the foot as a syenite porphyry—though the variation is not large. For these deposits Bäckström and later De Launay would assign a pneumatolytic-aqueous origin, according to which the iron was brought up in the form of vapors and precipitated at the surface in the presence of water during the interval of the two porphyry eruptions which are believed to have been submarine. This explanation involves the

activity of some metamorphic agency sufficient to change the original hematite or pyrite to magnetite. Its application could hardly be extended to the other occurrences, which are inclosed by a single rock mass, a condition that is quite general in the magnetites of the Archean.

The visit to Kiruna and Gellivare was interesting furthermore for the insight it afforded in regard to the changes wrought by regional metamorphism. There can be no doubt of the fundamental similarity between the two localities as has been emphasized by Lundbohm.¹ At Kiruna, however, the ores and wall rocks have remained undisturbed since their formation; while at Gellivare the rocks have been so compressed and crushed that they have lost largely their original structures, and the magnetites with their included minerals have assumed a coarsely crystallized phase. To extend the comparison even further it may be said that our Adirondack magnetites illustrate the extreme effects of metamorphism, a more advanced stage than is evidenced by the conditions at Gellivare. Here, the rocks only seldom show anything in the way of structures that can be taken as original, they are interfolded in the most intricate manner, and the ore bodies are of the most varied and complex shape. Yet in these features they appear not more removed from the Gellivare occurrences than the latter are from the Kiruna deposits.

The excursion through central Sweden, which followed the close of the sessions in Stockholm, afforded opportunity for a brief visit to the Dannemora, Norberg, Flogberget, Grängesberg and Långban iron mines. The writer did not continue with the party to Persberg and Taberg, but instead made a trip to the mines at Striberg and vicinity which were off the route of the regular excursion.

The magnetites of this district present a great variety of characters and modes of occurrence, and it is impracticable in this place to do more than call attention to some features that have a comparative interest. Their investigation is attended with extraordinary difficulties, as will be appreciated by anyone familiar with the occurrences or with the painstaking work that has been done by the Swedish geologists in this field.

The Precambrian complex that contains the magnetites is an intricately involved assemblage of gneissoid and massive igneous

¹ Sketch of the Geology of the Kiruna District. Guide to the Excursions of the International Geological Congress. Stockholm, 1910.

rocks, various uncertain gneisses, and an apparently sedimentary series represented by quartzites, schists and crystalline limestones, besides many rocks of merely local importance. The undoubtedly igneous types, which are generally later than the ore-bearing formations proper, include granites, diorites, feldspar porphyries and diabases, the last two occurring commonly in dikes that intersect the magnetite bodies. Of the gneisses a varied assortment exists: the prevailing members in vicinity of the ores are alkali feldspar-quartz rocks of strongly cataclastic textures and belong to the leptite group under the Swedish terminology. The use of the word "leptite" in Sweden is explained in the foregoing article by Professor Kemp. The term comprehends both granulite and the extremely dense hällflinta-gneiss. They range from granites to diorites in composition, but prevailingly carry some free silica. The nearest approach to this series in the Adirondacks is perhaps the gneiss surrounding the Hammondville magnetites which has been described by the writer.¹ The rocks of more or less sedimentary aspect seem to be relatively subordinate to those already mentioned, yet they inclose some large ore bodies. Their field appearance recalls the Grenville series of the Adirondacks. Of local prominence are amphibolites, usually feldspathic and with biotite or pyroxene and "skarn." (This very useful word is employed in Scandinavia for the aggregates of dark minerals—chiefly hornblende, pyroxene, biotite and garnet and their weathering products—that mark the borders of the ore bodies or occur as a gangue to the metallic minerals). As to the general method of distribution of the crystalline rocks in central Sweden, it may be said that the true granites constitute great masses which appear on the map as more or less rounded areas. The ore-bearing leptite and sedimentary rocks form belts squeezed in between or winding about the granite areas.

Grängesberg with its large bodies of apatitic magnetite stands apart from the other mines of central Sweden which we visited. It is rather allied, if any comparison be justifiable, to Gellivare and to our own apatitic magnetite occurrences as exemplified by Mineville. The resemblance lies not only in the mineral association peculiar to the ores, but is reflected as well in the larger features of the occurrence—the general uniformity of the surrounding gneisses, their predominantly sodic character, and the presence of granitic rocks, especially the pegmatites which border or interweave the ore

¹ Geology of the Adirondack Magnetic Iron Ores. N. Y. State Mus. Bul. 119, 1908, p. 45-49.

bodies. The Great Export pit with its broad lens of ore, rolling walls, pegmatite dikes and horses of country rock seems almost a physical counterpart of some of the Gellivare mines.

In an illuminative chemical and petrographical study of the Grängesberg area Dr H. Johansson¹ has found much to support the view of a magmatic origin for the ores. By reconstructing from chemical analyses a theoretical magma representing the average composition of the ore-bearing formation, he shows that it corresponds to a fairly acidic alkali granite with a predominance of soda over the potash element. The complex is characterized by rather strongly contrasting rock types from a chemical standpoint which correspond to the cleavage products of such a magma under a discontinuous process of differentiation. As extremes of the series we have on the one hand the granulite and gneiss group with 68 per cent or more of silica, and on the other hand the amphibolites with 50 per cent silica, with only few intermediate types. The ores that separated out during the differentiation show consistent relations to their inclosing rocks. The skarn ores are peculiar to the soda granulites; the apatite ores come in the plagioclase gneisses and granulites of more basic composition; and the quartzose ores are found with the potash granulites.

The ores of Grängesberg, as illustrated in the Export mines, which are much the largest of the group, are granular mixtures of magnetite and apatite. The latter amounts perhaps to rather more than 5 per cent of the whole. In some smaller mines of the vicinity hematite is the chief ore, and it occurs in one part of the Export mines, constituting the western half of the large northern deposit. It usually carries some magnetite and apparently grades into the latter. An explanation for its presence, which has been noted also in connection with the Gellivare deposits, is not easily found. The hematite is not a produce of later weathering, at least that derivation does not appear probable. The occurrence of hematite as a primary constituent of igneous rocks may be conceded, but its accumulation in quantity in the deep-seated zone by magmatic differentiation would hardly be expected.

The included bands of country rock are a curious feature of the larger ore bodies. They trend generally in the direction of the strike but may send off branches and coalesce with the foot or hanging wall so as to form a network separating the ore into

¹ Die eisenerzführende Formation in der Gegend von Grängesberg. Geol. För. För. Stockholm, 1910.

innumerable small lenses. The division of the ore and wall rocks is, however, quite sharp.

At Dannemora, Norberg and Långban we saw some typical deposits of such low-phosphorus ores as have been the mainstay of the Swedish iron industry since the middle ages. The association of magnetites with limestones, observed in some occurrences, has few parallels apparently outside of Sweden, and there are no similar deposits, of any importance at least, within our own State.

The Dannemora deposits have the form of vertical shoots, or stocks as they are referred to by Professor Sjögren in the guide to the district, and occur within a small belt of dolomitic limestone that is in turn surrounded by gneiss. The limestone belt is scarcely two miles long and a quarter of a mile wide. The gneiss belongs to the hälleflinta variety, with a dense ground mass, and is believed to be a crushed quartz-porphry. Of later age than either of these rocks are granite in large intrusions and dikes of several kinds, the latter only coming in contact with the ore. The magnetite is mixed with silicates, chiefly amphibole and pyroxene, and much of it is too low grade to be used directly in the furnace. Like many of the low-phosphorous ores which we saw, it has a very fine texture.

A somewhat related occurrence of magnetite is represented by the southern mine group (called Klackbergfältet) at Norberg. Lenses of dolomite are included in a fine-grained gneiss (leptite) and together are arranged in a discontinuous belt that follows the general country strike. Smaller lenses of magnetite are found here and there either wholly within the dolomite or along its contact with the gneiss.

The ores are high in lime and contain several per cent of manganese in the form of carbonate. An unusual ingredient of magnetites, noted in this place, is graphite which coats the natural joint surfaces so that the ore when seen in mass looks like so much coal.

The phosphorus content is remarkably low, on the average about .002 or .003 per cent. The iron runs from 40 to 50 per cent, but as there is an excess of fluxing constituents the grade is really better than the iron percentages indicate.

Another series of magnetites at Norberg is represented by the skarn ores which are directly bounded by leptite or else form pockets and irregular bodies within lenticular masses of the same skarn minerals that compose the gangue. These minerals are chiefly amphibole, pyroxene and garnet. The association and the presence of considerable calcite at times suggest that the deposits are geneti-

cally related to the former group, but that in this case a more complete alteration has been effected, leaving little trace of the original limestone walls. The occurrence has some analogy to the magnetites in the western Adirondack region, notably the Fine and Clifton ore bodies, which have been described by the writer¹ as a separate type from the magnetites of the eastern and northern Adirondacks. Professor Sjögren has called attention to the Tilly Foster mine of Putnam county as an illustration of the skarn magnetites, finding a complete agreement in the mineral association with the Nordmarken occurrence in Wermland. The Cranberry deposits of North Carolina, described by Keith, are also placed by him in the same class.

The quartz-banded specular hematites at Norberg, also seen by the writer in their typical development at Striberg, are remotely, if at all, comparable as to physical features with any deposits in this State. They consist of finely-divided hematite, subordinate magnetite, and quartz, with a lamellar and oftentimes banded structure due to the alternate arrangement of ore and gangue minerals. This structure may have all the regularity of bedding and has been frequently cited in support of a sedimentary derivation of the ores. The wall rock is leptite, with more or less mica in addition to the usual quartz-feldspar aggregate which characterizes that rock.

At Långban we found iron and manganese ores forming lenses and shoots in dolomite surrounded by granitic gneiss, leptite and diorite. The iron and manganese are not intermixed, as in the similar occurrence at Norberg, but are distributed in separate though often contiguous bodies. The shoot shape is most characteristic. A series of altered trap dikes (called sköls, a name applied also to zones of shearing or jointing accompanied by decomposition) seems to be related to the ore deposition, a very interesting feature to which Mr H. V. Tiberg, the manager of the mines, directed our attention. On the upper side of horizontal dikes the shoot may flatten out into a sheet to diminish or disappear below them, suggesting that the mineralization has been due to underground circulations after the intrusions took place.

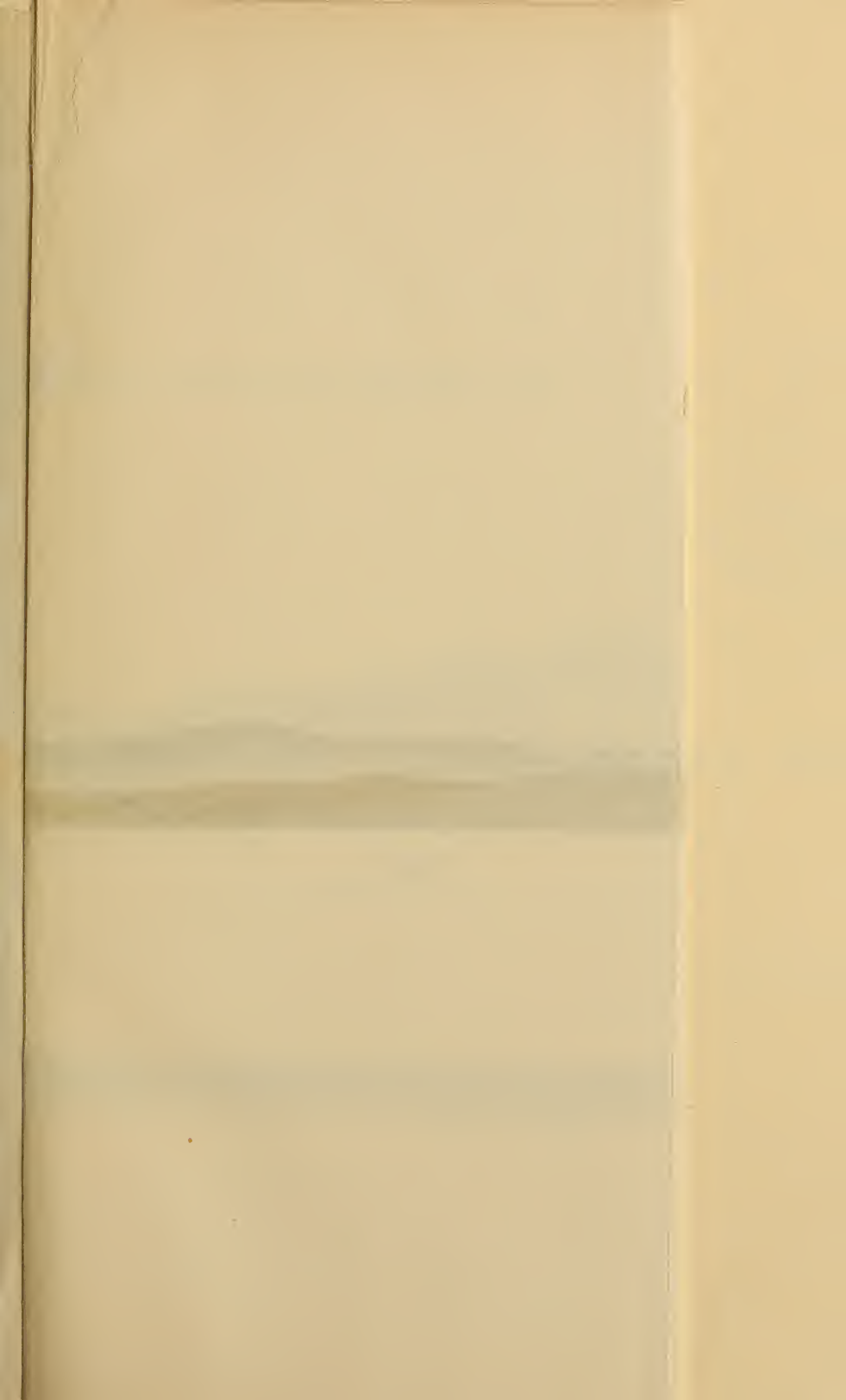
This brief survey of a few of the central Sweden mines will serve to show the complexity of geological and mineral features which characterize the ore occurrences in that district. As a whole the deposits are fairly distinct from those found in the Pre-

¹ Geology of the Adirondack Magnetic Iron Ores. N. Y. State Mus. Bul. 119, 1908, p. 37-42.

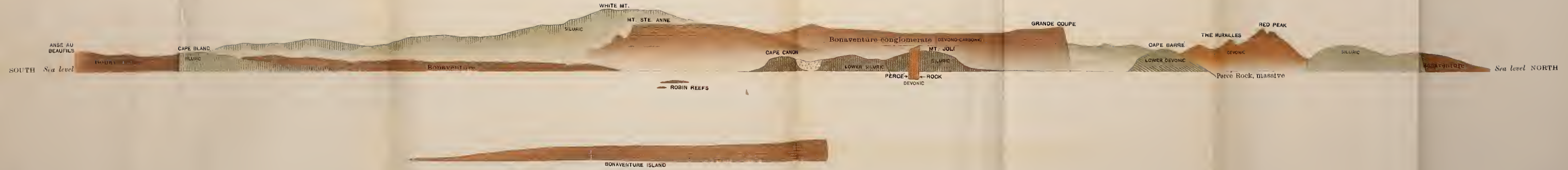
cambric of New York, or the adjacent areas, though between individual mines of the two regions certain similarities may be apparent or genetic relationships indicated.

The origin of the central Sweden ores is a question still under debate by the geologists of that country. The sedimentary view, which seems to have been the first to gain prominence in the Swedish reports, as is instanced also in the literature of our own Precambrian magnetites, apparently has lost favor among the recent workers in the field. Of these, Doctor Johansson, whose paper on the Grängesberg mines has already been quoted, and Professor Sjögren, in his recent contributions, have emphasized the inadequacy of the sedimentary theory as applied to most of the deposits. The present tendency, judging from the later researches, is to consider the deposits as magmatic segregations—an explanation more suited perhaps to the high-phosphorus ores which are included within the granulitic gneisses—or as the result of metasomatic processes that may have accompanied the neighboring igneous intrusions. The latter explanation applies with special force to the skarn ores and those found in limestone; while the silicious banded hematites are possibly to be excepted as a separate class with sedimentary affinities. The subject, however, is too intricate to be given further attention in this summary.

The writer wishes here to express his obligations for the guidance and many courtesies that he received during the excursions. It is needless, perhaps, to say that the visits both in Lapland and in central Sweden were crowded with interesting features, scientific and technical, which have found no place in the foregoing notes. To the leaders of the excursions, Doctor Lundbohm for Lapland and Professors Sjögren and Petersson and Doctor Johansson for central Sweden, and to Mr Per Larsson, manager of the Striberg mines, an especial acknowledgment is due.



PANORAMA SKETCH OF THE SEA FRONT AT PERCÉ



NOTES ON THE GEOLOGY OF THE GULF OF ST LAWRENCE

BY JOHN M. CLARKE

As opportunity has afforded during the summer months the writer has continued his observations on the geology, principally of the Paleozoic formations, lying about and within the Gulf of St Lawrence. Not all the notes and records made are yet properly digested and fitted into their sequence in the geological history of this region, but there are some which extend and fortify my earlier researches and others which illuminate the investigations of earlier workers in these fields. The more tangible of these records are here brought together as an expression of progressing knowledge which it may be hoped will eventually give us a clearer conception of the development of this interesting region and of the causes producing the gulf itself.

I

THE RELATIONS OF THE PALEOZOIC TERRANES IN THE VICINITY OF PERCÉ

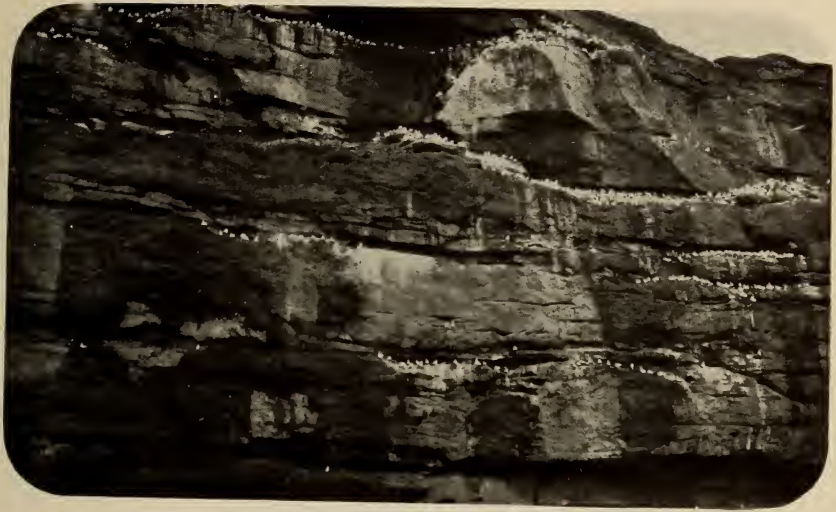
Percé is a region of boundless geological variety and interest. The writer feels that he has, in previous publications, only intimated its history, the details of much of which must be left to future students of the region, particularly that part of it lying back of the coast mountains. But in order to portray in panorama the relations of the Paleozoics here represented in a way that may help to clarify the situation, in the accompanying sketch a liberty has been taken with this irregular coast line by stretching out all its angles, headlands and bays into a straight line, so that, regardless of the unavoidable distortion involved, the eye may grasp not only the attitude of the rocks but their relative history. This section, which will be taken as only an approximation to accuracy of expression and whose discrepancies are freely avowed because of stretching a right angle into a straight line, is about six miles in length, unequally foreshortened at the north end, and extends from near Cannes des Roches at the north to the vicinity of l'Anse au Beaufils at the south. The point of view is out to sea east of Bonaventure Island, from the edge of the 50-fathom line which along this stretch of coast makes a deep bay inward toward this island (see Hydrographic map, p. 14, N. Y. State Mus. Mem. 9.

v. 1 Early Devonian of Eastern North America, 1908). This 50-fathom line is a submarine terrace at this point, one of the steps leading down to the great cut in the Bonaventure rock plateau made by the channel of the St Lawrence river. What is actually exhibited in this sketch is the present stage of the attack of the gulf waters on the folded and unfolded rocks of Percé, supplemented by the outstanding fault faces of the mountain cliffs and by the general effect of weathering denudation.

A contrast of fundamental moment lies in the attitude of the younger and older rock beds; the former horizontal or gently undulating, the latter simply inclined and, on the south front, vertical. A fact of similar moment is that the latter, consisting of Lower and Upper Silurian and Lower Devonian, are exposed in jutting cliffs by the removal of the mantle of softer beds from over them.

Bonaventure sands and conglomerates. These beds lie today much as they were originally laid down in the shallow waters of a rough coast which must have been not greatly unlike, in its broken rugged cliffs, the coast of Percé as it is now. I believe the Bonaventure series of beds, at least so far as we can distinguish it from the Gaspé sandstone series, or so far as it can be defined from its original section on Bonaventure Island, represents in time the latest stage of the Devonian and possibly the earliest of the Carbonian. We can not prove the latter affiliation from any evidence around Percé, nor indeed is this age demonstrable from intrinsic evidence at any point throughout its distribution from Gaspé bay to the head of the Bay of Chaleur. We have been in the way of deferring to current opinion in this matter, but can now go no further than to recognize an interval between this deposit and the earlier Devonian of the country, often intensified by down-faulting, the absence of any marine later Devonian and the continuity of this mass of sands and conglomerates as an accumulation of landwash along a bold upturned Precambrian and early Paleozoic coast. I have had occasion before to refer to the fossil-bearing pebbles of this conglomerate,—Cambrian, Silurian and Devonian; heads of Halysites often of large size (that here figured is from the cliff face on Bonaventure Island); fragments of the Gaspé sandstone and of the Percé Rock massive with their characteristic species. There is some order in the assortment of these pebbles, for there are as a rule few jaspers and other crystallines mixed with the limestones and few fossil-bearing blocks where the crystalline pebbles abound. Logan records a block in this conglomerate weighing upward of eight tons, but while such large ones are not familiar to my observation there is plenty of

Plate 1



Bonaventure conglomerate; Gannet cliffs of Bonaventure island

similar evidence that large, usually angular, masses were thrown down by seasonal freezing and thawing in the sea cliffs of those old days.

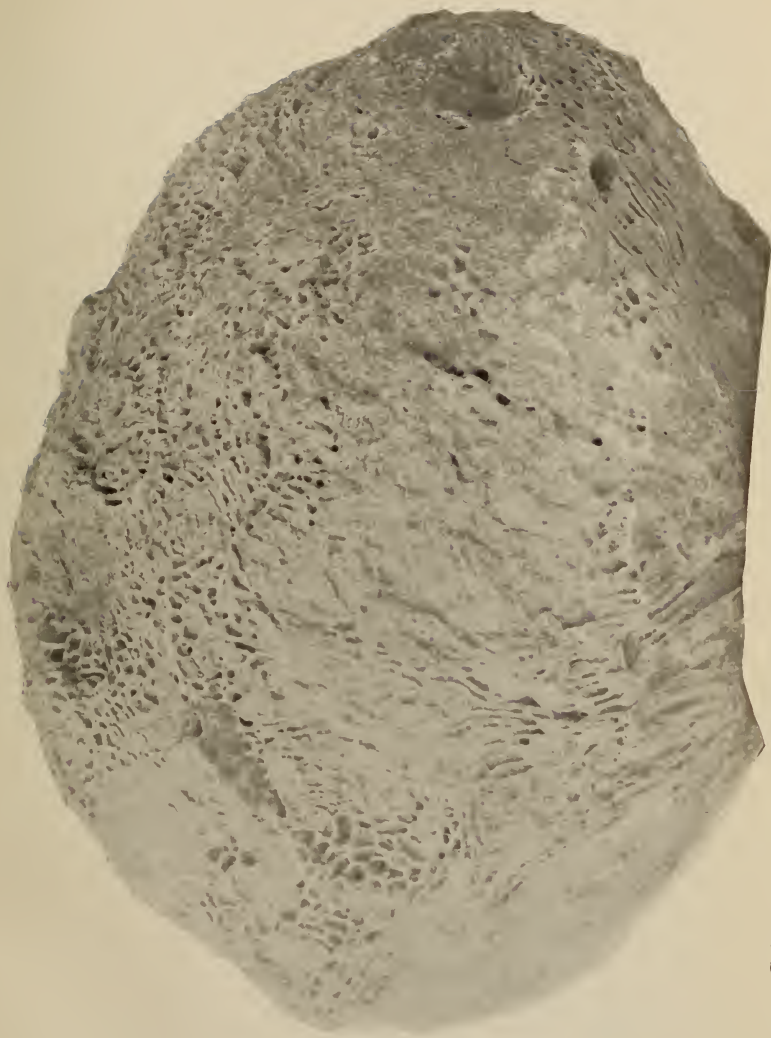
While these red Bonaventure rocks have undergone but slight deformation, it is their noteworthy down-faulting that has given to Mt Ste. Anne and its outlying cliffs their peculiar impressiveness. Ste. Anne rises, back of the sea cliffs and terrace of Percé, in a vertical east face from which has parted and, as I take it, slid down to lower level, that portion of the original mantle represented now by Bonaventure island and by the Robin reefs which the waters of the "Channel" have not yet washed away. Ste. Anne was once the "Table-a-rolante," and its gently rolling surface slopes downward to the north; but passing this, the observer is abruptly confronted by a second majestic fault scarp, the Grande Coupe, over whose smoothed face the water falls in vertical wavering lines to a level as low as the road, thence following to the sea a second fault plane which traverses the older rocks in a line at right angles to the Grande Coupe. This scarp faces north. Again at the back of Ste. Anne facing the south and west is an even more impressive fault cliff, the "Amphitheatre." Cut off thus by three bold fault faces, this mass of Bonaventure conglomerate is peculiarly isolated. The mountains roll up to greater heights westward of these undulating surfaces of Ste. Anne, but except for the first range, known as White mountain, their composition is as yet little understood. There is no area of these Bonaventure rocks known to me along the coast from there up the Bay of Chaleur, where this mode of bold faulting has been repeated, nor is there any very satisfactory evidence that the down-breaking of Mt Ste. Anne on at least three sides has involved the lower rocks on which it rests. These lower and older rocks constitute the very heart of appalachian up-folding and made a most irregular and unstable floor for the conglomerates, which may account for the manner in which the mantle has broken asunder without great distortion. Remnants of the down-thrown blocks still lie on the land; one constitutes the shore front in a strip reaching from the Robin beach south to Birmingham's hill; another lies beyond the vertical limestone of Cape Blanc, where there is a sharp fault against the latter, with evidence that the edges of the conglomerates have been dragged downward; again, way at the north end of the section at Cannes des Roches, is a tipped block lying at fault with the Siluric, while the very top of Red peak, the highest point overhanging the Malbay, seems to be an outlier of the Bonaventure limestone-conglomerate resting on

the upturned angles of the Percé Rock Devonian; this too has presumably been separated from the parent mass of Ste. Anne by a fault.

One additional fact is here worthy of record. Overlying the slopes of Mt Joli, particularly the south flank, is a very thin mantle of a gray unfossiliferous shale, whose attitude is apparently at right angles to those vertical beds. What is present is a mere residuum reduced to little more than a film but it seems to be a remnant of some gray shale that pertained to the Bonaventure series and has been broken up by weather. I would make this intimation with reserve, as it is possible that this thin accumulation has some later origin.

The vertical rocks. It is in the matter of attitude that the great contrasts of this coastal geology lie. On all the southward stretch from the angle of Mt Joli, the old rocks are but very little out of the perpendicular, standing with an inclination of 80° - 85° s. This is true of all the Siluric shales and thin limestones of Mt Joli and Mt Canon, of the highly colored Devonian of Percé Rock and of the red and white limestones of Cape Blanc. On the north limb of the coast angle these older strata are less uniform in attitude and more faulted against each other but all steeply inclined. Throughout the complete series, however, there is a multitude of displacements, to which I have previously given some attention. Denuding these earlier rocks of their overburden, one finds the basis on which to restore the pre-Bonaventure Appalachian upfolding, which has received its essential shove from the south, as the arm of the great mountain system here curved itself toward the east. All the capes and promontories of the coast lie where the more durable vertical rocks have stood against the sea, while the softer Bonaventure mantle was destroyed. These various Paleozoic rocks and their contents have been already pretty freely discussed by the writer and on this occasion it is desired only to consider somewhat more fully the character of the *cliffs at Cape Blanc and their extension into the White mountain.*

The overlap of the red Bonaventure sands and conglomerates on these vertical limestones is beautifully seen on this sea front. Unfortunately these cliffs are very difficult of access except in a calm sea, for they run sheer to the water with only a little beach here and there north of the cape. From above they are quite out of reach. The northernmost part of the vertical series, especially where covered by the red Bonaventure, is deeply stained red and green, but the color has not been derived from the rocks above.



Colony of Halysites — a boulder from the Bonaventure conglomerate, Bonaventure island.
Length of original 10 inches.

Plate 3



Cliffs of Cape Blanc or Whitehead, Percé, viewed from the south. In the foreground horizontal red Bonaventure sandstone; the cape is composed of vertical gray-white Siluric-Devonic beds

The basal mass of the Bonaventure here is wholly of deep red, soft sands, the conglomerates not appearing for a distance of some 30 to 50 feet higher. The vertical beds below, beginning at the north, are alternating shales and thin sands with thin limestones, the shales dark, the limestone bands red, green or blue. Southward the color is lessened and the beds become a gray white as they approach the point of the cape where the lighthouse stands. Beyond the cape the white beds and the entire series is terminated by down-faulting against the red Bonaventure rocks beyond them. The thickness of this vertical series of limestones is from 1500 to 2000 feet without much evidence of loss from internal faulting; and in attitude the beds fully conform to those of the Percé Rock and the Mt Joli series. I have before shown that the fossils of these beds are distinctively Siluric and the lists I have given indicate now a Lower Siluric age for the southernmost or whiter layers and a later stage for the northern, more highly-colored series. This condition, if correctly inferred, seems to imply an overturn of the strata, but much still remains to be learned from the fauna. The fossils are not especially abundant, not often clearly preserved and rather difficult to acquire, but the acquisition and subdivision of the fauna of the series remains an interesting problem. This limestone massive inshore affords exposures along Birmingham's brook and thence on toward Irishtown, rising gradually into the ribs of White mountain, skirts the rear of the Ste. Anne plateau in higher elevations, shows itself at Corner of the Beach and comes out to the Malbay shore in that vicinity (shown on the section here at the north end). It thus encircles the entire series of Siluric, Devonian and Bonaventure rocks about Percé, and forms the outstanding wall of an ancient basin within which the Bonaventure rocks were here laid down. We have as yet no reliable evidence that these Bonaventure deposits extended westward beyond this rock wall.

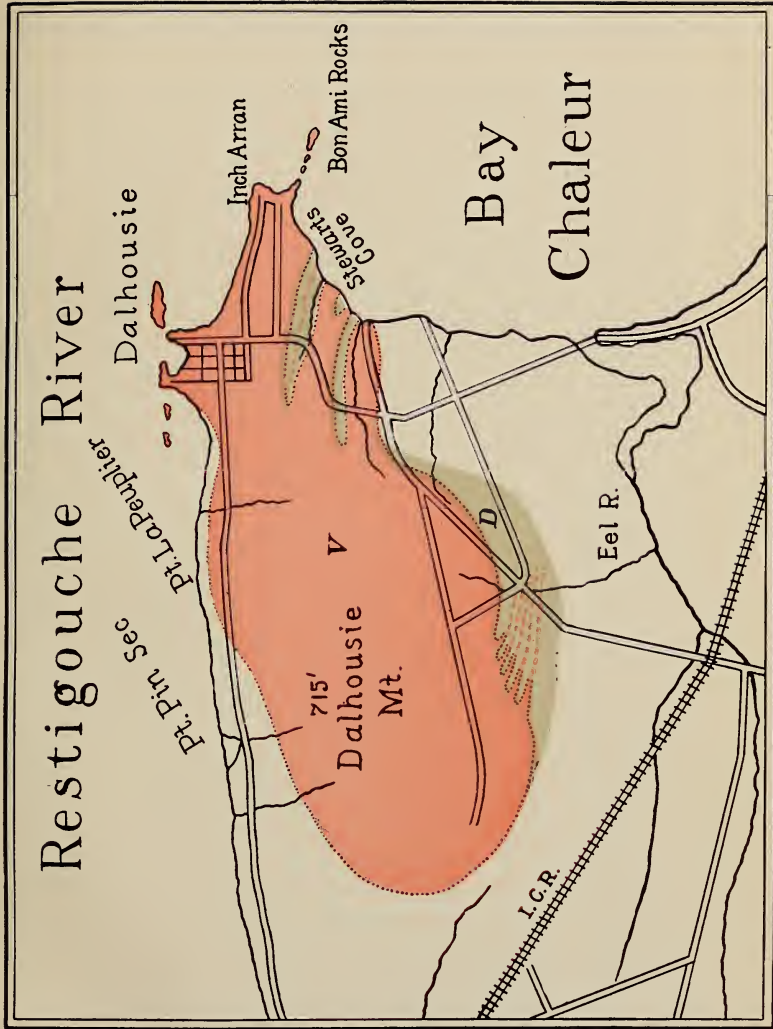
II

ERUPTIVE CONTACTS IN THE MARINE DEVONIC DALHOUSIE BEDS AT DALHOUSIE, NEW BRUNSWICK

This mass of soft and highly fossiliferous shale has been described at length and its fossils fully discussed in the second volume of my memoir on the Early Devonian of Eastern North America (1909). I have more recently had opportunity to examine the extension of these beds from the shore exposure at Stewart's cove, inward or westward toward Dalhousie mountain. It is

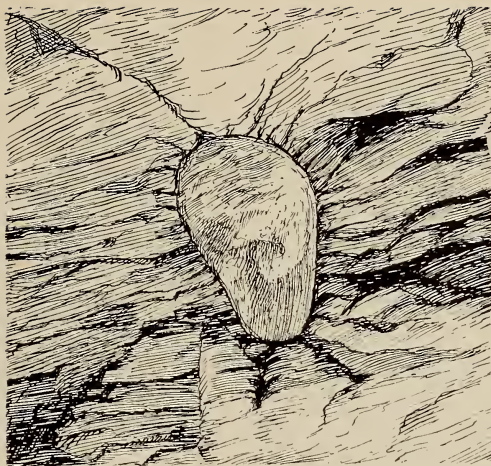
necessary here to restate briefly the interesting geological relations in order to bring out the pertinence of my present remarks. Dalhousie mountain lies a mile or so back from the shore of the Bay of Chaleur at Dalhousie and appears to be a large boss of eruptives from which apophyses extend eastward into the sea, a large arm reaching down through the village and projecting as two points at the waterfront, thence extending continuously to the lighthouse at Inch Arran, covering the Inch Arran beach, including the islets known as the Bon Ami rocks, and therefrom reaching to the opening of Stewart's cove. This heavy lava mass is interesting for its great inclusions of crystalline blocks which are finely displayed in the bluff below the Inch Arran light. These inclusions are of various composition, pink and gray syenites prevailing, and in this much weathered rock face where the decomposition of the lava has spread radially from their surfaces, the cliff looks as though it had been shot full with great missiles whose impact had fractured the matrix.

At the south end or bottom of this mass begins an exposure of the upper inclined fossil-bearing Dalhousie shales, the contact being buried under the beach sand and the highest beds, which are coral limestones, being exposed only at extremely low water. Continuing several hundred feet along the shore cliff wherein are one or two thin ash beds, the shale series is cut by a second volcanic mass at the mouth of Stewart's brook where the contact is sharply defined and its effects manifest. The front of this second volcanic mass is a fifth of a mile long and near its midlength lies a large but quite clearly embedded mass of the shale, whose precise position in the series is not entirely certain. At the bottom or south end of this lava mass the lower section of the shale series appears and continues for several hundred feet more. Its base (beds with *Gypidula pseudogaleata*) lies on a floor of volcanics which, on the shore section, terminates the sedimentaries. The entire section of Devonian sediments here is measured at about 450 feet, without evidence of repetition in its parts, and it is actually cut but once by the volcanics. These extrusives were contemporary with the deposition of the sediments, and it seems probable that they are actually connected as apophyses with the mass of Dalhousie mountain as represented on the original map of this region by Dr R. W. Ells (1884). Here on the shore front the volcanic masses are very heavy and their contact effects are shown by the induration of the shales, the whitening of the calcareous fos-



Sketch map of Dalhousie showing the relation of the eruptive mass (V) and its apophyses to the Devonian marine sediments (D)

Plate 5



Inclusions of syenite in the diabase at Inch
Arran light, Dalhousie

Plate 6



Dalhousie—Gateway to Fossil cove—an arch of eruptive rock



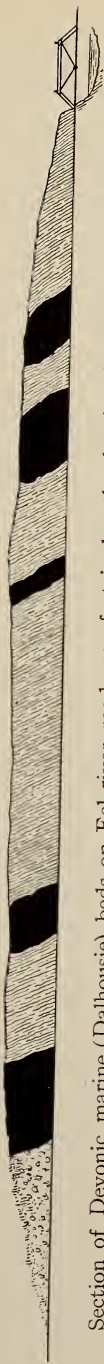
Dalhousie—Fossil cove at very low tide exposing about 25 feet of strata at the top of the series, largely coral beds not before recorded. The pick is resting on the uppermost layer.

Plate 7



Contact of fossil-bearing beds (above) with the eruptives (below). The soft calcareous shales are baked into limestones. Fossil cove, Dalhousie.

Plate 8



Section of Devonian marine (Dalhousie) beds on Eel river road, 202 feet in length, showing five interbedded masses of volcanic tuffs and ashes. The dip of the unaltered fossiliferous beds is indicated and is to the north.

sils and the deposition of secondary calcite. There is no breccia formed as the sediments were not sufficiently hardened at the time of the outpours to produce a breakage of this character.

Back on the heavily wooded mountain there are no traces of any other rock than the eruptive and the only clues that I have obtained as to the inward extension of these almost ruined masses of Devonian rocks are located along the road southward to Eel river, which runs with some deviation parallel to the coast but at a distance of three-fourths to one mile back. The rock cuts along this road complete without simplifying the relations of the sedimentaries and eruptives.

Sediments and eruptives in the Eel river road section. On consulting the adjoining sketch map there will be seen an east and west crossroad reaching from the shore to the Eel river road and passing along the main eruptive mass. Turning south on the Eel river road the remaining width of the volcanic is soon passed and the road cuts a series of red sandstones, followed by dark reddish shale and yellow decomposed limestone. The shale has produced a peculiar fishplate which competent authority has thought may be *Pteraspis* or an ally, and the decomposed limestone is profuse in Ostracodes, of which there is abundance in similar position on the shore section. The shore, however, has produced no red sandstone, no reddish shale and no fish remains. The outcrop of the sedimentaries is here not more than 50 feet in entire length; then follows the eruptive which is not interrupted until the road crosses the bridge over Stewart's brook and in a west curve takes the next rise. In a position which corresponds to the lower or south section on the shore there is shown in this road a slight extent of similar Devonian shale. From this point on, all correspondence in the shore and road section is lost, for on the shore the sediments have ended. One continues on the highway, however, over the hill, crossing the second bridge beyond the house of James Stewart and here begins the section which is seen in diagram on the following plate. Here the outcrop face is 202 feet long; its sediments are all normally and steeply inclined to the north as on the shore and are crossed by *five* distinct beds of contemporaneous lavas, tuffs and ashes. The contacts of the sedimentaries with these thin ejections are absolutely unaltered; indeed here, as on the shore section, there are ash beds in which the fossils lie unaffected. Evidently the thin volcanic masses carried too little heat to effect any change in the sediments lying in cool

waters, only the heavier outpours seen on the shore section radiating enough heat to produce any contact changes.

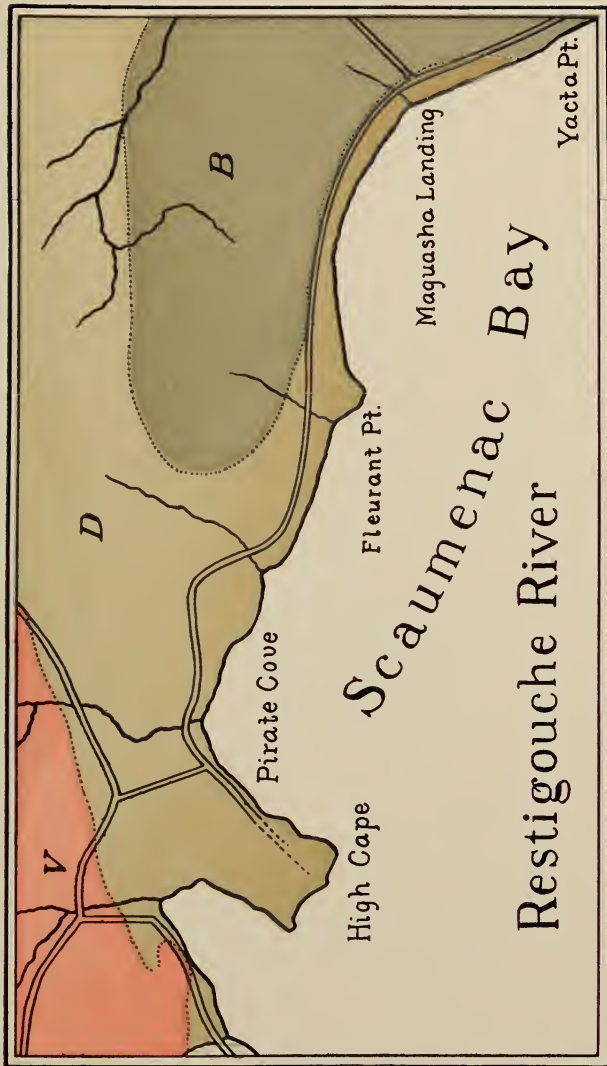
On the accompanying sketch map the distribution of the sedimentaries and their accompanying volcanics are indicated as now known. It presents an occurrence of singular and unusual interest.

III

STRATIGRAPHY OF THE DEVONIC FISH BEDS AT MIGOUASHA, PROVINCE OF QUEBEC

The fish-bearing beds of this region are probably the most remarkable of any Devonian deposits known in respect to the abundance and excellent preservation of their fish remains. These have entered into the literature of paleontology extensively and generally under the name of the fishes or beds of Scaumenac bay, Escuminac, Fleurant point or Yacta point. In view of the polynomial character of the region it is well to be explicit. These beds lie on the north shore of the Restigouche river where it broadens into the headwaters of the Bay of Chaleur. Their location is straight across the water from Dalhousie, N. B., whence a ferry runs to what is known as Migouasha landing, where the rock wall of the bay is degraded to the water. At a quarter of a mile east of Migouasha landing the red rocks of the "Bonaventure" formation come down to the water in an eastward dip, and at about three-quarters of a mile westward of the landing is the projection of Fleurant point. The high-colored "Bonaventure" beds rising from the water line at the east, present a contact with the underlying gray fish-bearing beds for a distance but on passing Migouasha they retreat into the hills of the background and all the rock beds exposed thence westward to Fleurant point are the gray sands and shales with fish. In the voluminous literature relating to the contents of these rocks little has been recorded as to their stratigraphy and the essential evidence which has led to their general acceptance as Upper Devonian has been brought out by Doctor Ells's account of the locality given thirty years ago. These gray Devonian sands with their nodules of various sizes, carrying *Bothriolepis*, *Scaumenacia* and several other fishes in extraordinary preservation and the blocky masses filled here and there with their remains, attain a considerable thickness at the highest point along the stretch of coast, perhaps a clean exposure of 100 feet and, in view of their dip eastward, a total thickness of not far

Plate 9



Sketch map of the Devonian fish locality at Migouasha. V=Eruptives; D=Devonic; B=Bonaventure

from 200 feet. This region is the Scaumenac bay of the reports. I have no fault to find with the determination of the age of these beds as Upper Devonian; not only geological relations indicate this but Doctor Eastman states that the composition of the fish fauna itself substantiates this reference. There is something to be said both for and against the assumption that the "Bonaventure" conglomerate of this part of the coast is wholly Carbonic; in fact in its typical development where it fronts the gulf at Percé, it certainly seems to complete the late Devonian interval.

My attention has been attracted to a layer of loose rounded boulders which underlies the fish beds along the shore not far west of Migouasha landing. It is a rather striking accumulation lying together like a mass of till with the boulders rolling out into the landwash. These boulders, which are largely limestone, contain a variety of invertebrate fossils. Some blocks consist only of colonies of Halysites; another single boulder contains *Dalmanites micrurus* Green (head and pygidium), *Camartechia* cf. *dryope* Billings, a small *Leptostrophia*, *Chonetes* and *Pholidops* and a rather striking species of *Cyrtodonta*,¹ which indicate a normal marine early Devonian fauna. The boulders and their contents are comparable to the limestone pebbles and boulders of the red conglomerates (Bonaventure) of Percé, though the gray color and comparatively slight thickness

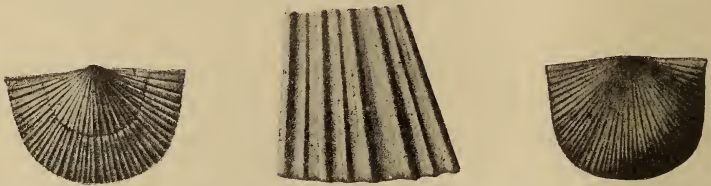
¹*Cyrtodonta gratia*—an oblique shell with very low convex valves, not expanding behind, very slight forward extension, giving thus an outline quite usual in the genus though perhaps somewhat less orbicular than in the few species now known in the Devonian of the Atlantic province. The



Cyrtodonta gratia nov. Exterior of right valve and internal cast showing the character of teeth

exterior is closely lined concentrically. The anterior muscle scar is deep and the umbonal teeth strongly developed into a comblike arrangement in which the first and third anterior teeth curve toward each other, enfolding the second; behind these six lesser teeth diminishing in size to the umbo.

of the mass forms a strong contrast. Of course the age of the fish beds depends on the age of the youngest fossil to be found in the boulders of these underlying beds and as yet I have seen nothing later than the Helderbergian. It is therefore possible that the sedimentation of the fish beds began before the opening of the stage we should elsewhere characterize as Upper Devonian. An additional supplementary fact is worthy of record. A large angular block of highly argillaceous black limestone, with a weight of several tons lying on the Migouasha beach above the reach of high tide, has every appearance of having been derived from the rocks of these near-by escarpments. This block contains in some abundance a brachiopod of the genus *Schuchertella*, and though I have not been able to identify it with species known to me, it is evidently of early Devonian type. Figures of this species are here introduced and the distinctive characters may be



Schuchertella sp. Ventral and dorsal valves with enlargement of the surface.
From the shore at Migouasha

given as the coarse, wide apart, rounded ribs, with flat interspaces divided in later growth by intercalary ribs, all the interspaces being traversed by fine longitudinal lines.

IV

HISTORICAL NOTE ON THE LEAD MINES OF GASPÉ BASIN

In my writings on the geology of Gaspé, reference has been made to recent and present attempts on the peninsula of the Forillon to exploit for galena and silver the little calcite seams which fill the joint crevices of the Lower Devonian Grande Grève limestone beds. These efforts began far back in the history of New France and the most serious of them, as well as the most productive, was at Little Gaspé close to the contact line of the limestones with the overlying Gaspé sandstone. It is a singular illustration of the undying persistence of legend in the face of well-established fact that a forlorn hope early dismantled should have revived and been persistently pursued for well nigh 250 years.

Plate 10



Boulder bed with interstratified sands lying beneath the fish-bearing beds at Migouasha. These boulders abound in Devonian and Silurian fossils.

Some years ago there was found among the departmental archives of the Seine-Inférieure at Rouen the manuscript journal of Jean Doublet. This was edited and published by Charles Brèard in 1883 under the title "Journal du Corsaire Jean Doublet de Honfleur, Lieutenant de Frégate sous Louis XIV." Doublet was a freebooter whose stirring life has put a thrill into every page of this remarkable book. He was the son of François Doublet who in 1663, under concession from the Company of New France, attempted to settle the Magdalen islands and disastrously failed in every respect save that of giving to these islands the name of his wife Madeleine. When this expedition to the Magdalens took place Jean Doublet was seven years old and the little fellow stowed himself away on his father's ship as it left the roadstead of Honfleur, only allowing himself to be discovered when a boatswain into whose bunk he had crawled threw himself down on top of the sleeping boy. The vessel was then well out to sea and the angry father had to take the boy along with him to the Magdalens, fortunately indeed, for it is to him we owe practically all we know of this attempt to colonize those islands. Returning to France at the end of the season, full of promise of success in the fisheries there, the elder Doublet came back to the islands in the spring to find his colony broken up, his stores pillaged and the place wholly abandoned. So this attempt ended in disaster. In 1665 François Doublet, the father, was commissioned by the Compagnie des Indes Occidentales to go for them to the coasts of Gaspé to examine a lead mine about which reports had come to France through the Intendant Talon. M. Brèard says in a note quoted from the Archives de la Marine, Canada (1665), that Talon, judging that the discovery of precious or even base metals was a matter of importance to the king, obtained the right to send to Canada forty workmen. The company recruited these in Normandy and the command of them was given to François Doublet. In addition to the lead, the ingénieur-fondeur believed he had discovered silver on the coast of Gaspé. "The belief seems well founded," wrote Talon.

In "Sketches of Gaspé" (1908) I quoted Nicholas Denys's remarks on this Gaspé mine (1672) in which he says he had known of the place for twenty years, that is as early as 1652, doubtless from reports communicated by the Indians to the missionaries. Indeed as early as 1663 Father Balloquet was sent to look up the place and, according to the Jesuit Relations, returned not finding his mine "good."

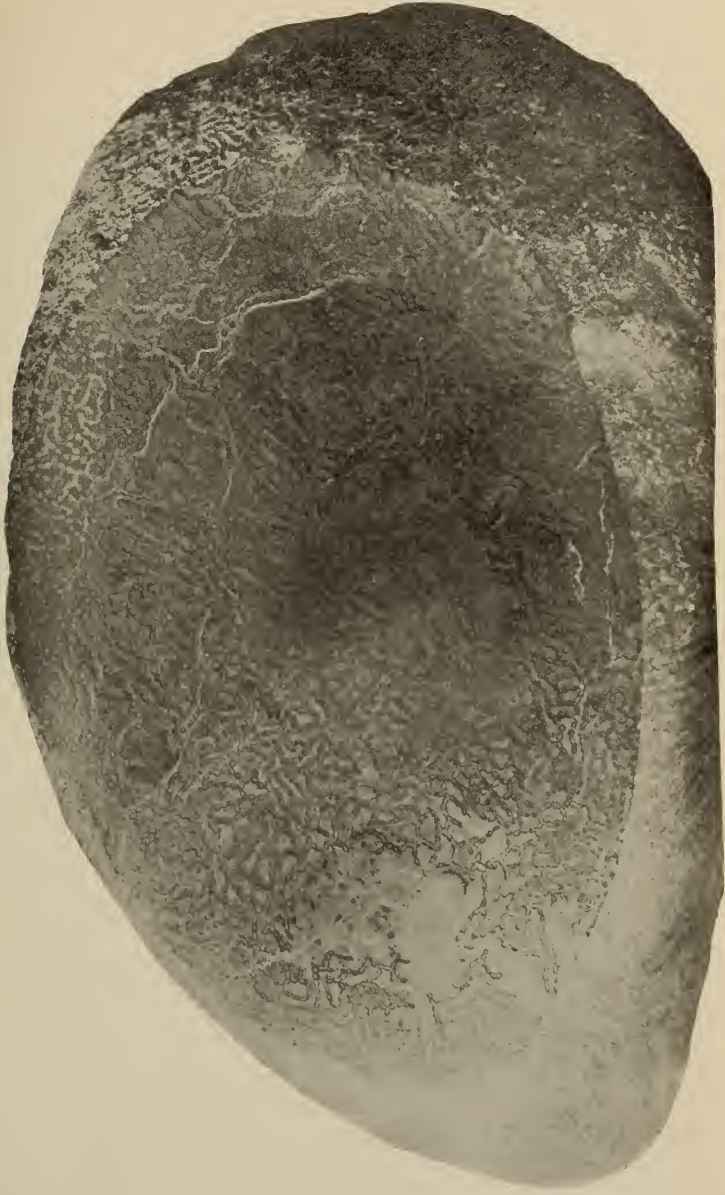
Jean Doublet gives this account of the mining in Gaspé:

In the year 1665, my father was asked by the Company of Canada¹ if he would go to Quebec on one of our vessels which would fit out at Havre, in the capacity of a commissioner to mine for lead along the shores of the river St Lawrence where discoveries had recently been reported. They promised to furnish him seventy men for this purpose and also a German mining engineer and an interpreter, all at the expense of the company, and to provide in general all tools and provisions as well as the necessary ships. My father was to have 3000 francs a year and 4 per cent of the profits on the lead; the engineer to have 4000 francs; the interpreter 600; the workmen in proportion. My father accepted the position which he would not have done had it not been for his previous losses. When the ship was in the roadstead at Havre ready to sail, a boat came to carry my father to it, as he was all ready; and I plead so well that I prevailed on both him and my mother to let me go with him; so we were taken aboard the ship which was commanded by the celebrated Captain Poulet of Dieppe. We found the vessel extremely crowded by eighteen horses and two stallions from the King's stables. The hay for the sustenance of these filled up the whole place. Then between decks there were eighty respectable young women who were to be married on our arrival at Quebec; all these together with our seventy workmen made a veritable Noah's ark.

Our passage was pretty fair, although it took us three months and ten days to arrive at Quebec. M. de Tracy was viceroy, M. de Courcelles was governor, M. Talon was intendant, M. de la Chesnèe-Auber was commissary general of the company. When my father had issued his orders a vessel of 70 or 80 tons was equipped to carry us with all our necessary things to the mines. On the 13th of August we arrived and disembarked at Gaspé and set to work on our lodges and furnaces. On the 28th we began to pierce into the rock on the south side where was the first discovery the native savages had made. These savages in making a fire for their kettles had used one of these rocks for a handiron (de chenet) and lead came out of it. This they found after their fire was extinguished and they took it to M. de la Chesnée who sent it to France. This it was that had occasioned our enterprise as it was thought that considerable of this metal might be found here as it is in England. On the 6th of September the said mine, after having been excavated 32 feet deep, was fired and we had two men killed and one named Doguet, of Rouen, had both his legs blown off, while three others were slightly wounded. This was their fault as they did not retire as far from the mine as they

¹ What is here meant is the "Compagnie de la Terre Ferme d' Amerique," reorganized by an edict of May 28, 1664, under the name "Compagnie des Indes Occidentales" (Brèard).

Plate 11



Colony of Halysites, from the boulder bed at Migouasha. Length of original 10 inches

were ordered to. At a depth of two feet this mine promised well as we found there eight inches and four lines of face. But after we had reached a depth of 32 feet, it ended in nothing. This discouraged the Sieur Vreiznic, our engineer, who said that in all the mines he had excavated even of two or three lines at the surface, he had found at a depth of 20 feet more than a foot of face without counting the veins scattered in various places.

From the 15th to the 24th of September we worked on the north side. After having removed the earth from the rock we found at the surface five inches, one line; and after the mine was opened there were found only two inches. From the 27th of September to the 4th of October we worked on the east side without losses or wounds to our men. We had some hopes of succeeding better here, since we had found on the surface nine inches and three lines, but at a depth there was nothing at all. And that we might have nothing wherewith to reproach ourselves, on October 28th we tried the west side, where on the surface were only two and a half inches, and at 20 feet depth nothing.

The season obliged us to return to Quebec as we had neither provisions nor lodging fitted to resist the great cold and snows; so we were forced to abandon our work which had yielded us no more than eight to nine thousand weight of lead. We took our departure on St Martin's day and on the same vessel that had brought us, and the mine had only made a hole in the purses of the miners.¹

¹ A play on words: "La minne mina la bource des mineurs."

OBSERVATIONS ON THE MAGDALEN ISLANDS

The Magdalen islands, lying in the very heart of the Gulf of St Lawrence, are a chain of disjected and sea-wracked remnants of continental land, standing today as they have stood since the beginning of navigation in these turbulent waters, a fearful menace to the sailor and his craft. The chart shows them stretched out like a long key lying crosswise of the waters in a direction which corresponds to the general northeast-southwest course of the basal rock folds and depressions which govern the fundamental contour of all the lands of the lower gulf. If the eye will follow the 20-fathom line on the chart, it will be seen what a tremendous platform has been carried away by the waves in the gradual wasting of the land to this slight depth and what slender, broken remnants of it now remain above the water line. A 20-fathom elevation to the water line would throw all the chain of islands into one land mass and leave them as slight elevations along the rib of a broad plateau which, altogether, would present many hundred times the area of the land now remaining. Even the 10-fathom line sweeps about all the islands, tying them into one, and reaches out to take in Brion island at the north and the Great and Little Bird rocks further east; so that if the water might stand now at this 10-fathom line, or in the days when it did so stand, the broader Magdalen island would stretch its key out into a long, slender and gracefully curved handle.

Today these islands differ only from the isolated rocks of Brion and the Birds by being fringed with sand spits and dunes and tied to one another by tremendous sand bars, which the seas at the east and the west have piled up into a double chain, leaving between the great interior lagoons, Basque harbor, House harbor, the Great Lagoon and its branch at the extreme north behind the dunes of Grosse Isle and East point. Thus the sea has tried to bury the remnants of its own destruction, tossing back to these feeble fragments of the land its very ruins.

Compared to the area of the Magdalen group as it appears on the chart, the actual area of rock land is small and resolved into little insular units of soil and of population. *Entry island* stands at the eastern terminus of the chain and faces the entrance to Pleasant bay, sometimes the least, and sometimes the most dangerous harbor on all the coast. Westward and separated from Entry by the tremendous spit of Sandy Hook is *Amherst island*, whose harbor and

Plate 1



Magdalen islands. Shore cliffs on Alright island; showing the contrasting colors of the soft and hard sandstones and the "demoiselle" topography.

landing at the little triangle of Mt Gridley the eye will barely catch except by close inspection of the chart. This little spot of rock is really cut entirely away from the island proper, but a sand bar leads across to Demoiselle hill and beyond this narrow neck of actual land the island widens out, extending east and west for nearly ten miles across, broken by demoiselle hills which have a trend parallel to the northeast course of the island chain. The two great bars which run north from Amherst and inclose the Basque harbor are cut across by tickles or gullies too narrow to make a passage except for the smallest craft at high water; but the inhabitants drive along these bars from island to island fording the tickles as best they can — always a perilous passage if the sea outside is heavy. Reaching out with these two arms Amherst clutches *Grindstone island*, an almost circular land mass with high shore cliffs on nearly every side, and again an interior of rounded demoiselle elevations, the nature of which we shall presently refer to. Then from Grindstone two arms again extend north and eastward.

At the west is the immense bar reaching 27 miles from Hospital cape to *Grosse Isle* inclosing midway of its course the little rock fragment, *Wolf island*. At the east Grindstone is separated from the land next north, *Alright island*, by the tickle which leads into House harbor, the best of the land-locked roadsteads of the island, and ferriage is necessary to reach the south end of the crescent-shaped film of land which makes Alright. This island is little else than a row of beautifully rounded demoiselle hills whose grassy green summits and gray sides form a brilliant contrast with the low-lying platform of red rocks at the water's edge. Perhaps two-thirds of the area represented on the map as constituting Alright island is rock land; the rest is sand and the great eastern bar here runs its course, passing the little rock called *Shag island*, on to the northeast until it is broken across by the Grand Entry, the broad tickle leading into the northern expansion of the Great Lagoon. This, too, is good harborage but the vessels in heavy sea or low tide rarely take the risk of running it. I have waited eight hours on the sands of Grand Entry for the coast steamer standing in the offing with an east wind and a falling tide, to muster courage to run the passage. From Grand Entry to Old Harry point is another sickle-shaped bit of land, cut into and perhaps in two or three by sand-covered passages. This is *Coffin island*, and on the sea front from here around to East point, the farthest tip of the islands, and back again to Grosse Isle, there is no rock land — all is a vast stretch of high duned sands. Behind these sands and facing the lagoon is the bit of land called

East island, with its high half-ruined North East cape which peers out far over the sands and is the first point of the islands that confronts the traveler from the north. There remains in this chain of sand, Grosse Isle, a divided island, one single hill standing out on the west coast as North cape, the rest a headland, Grosse Isle head, facing in a long escarpment the interior lagoon.

It is an instructive feature in the structure of these islands that the northern lagoon both south and north abuts against so many steep bare cliffs. The waters of this great lagoon are shallow and navigation in them is closely restricted to a narrow sinuous channel through whose course the navigator is guided by a staked way. These waters could not in their present condition have contributed to the downfall of the rock cliffs; the interior cliffs were made in days before the lagoon existed or its sands were heaped up to cut off the outer sea.

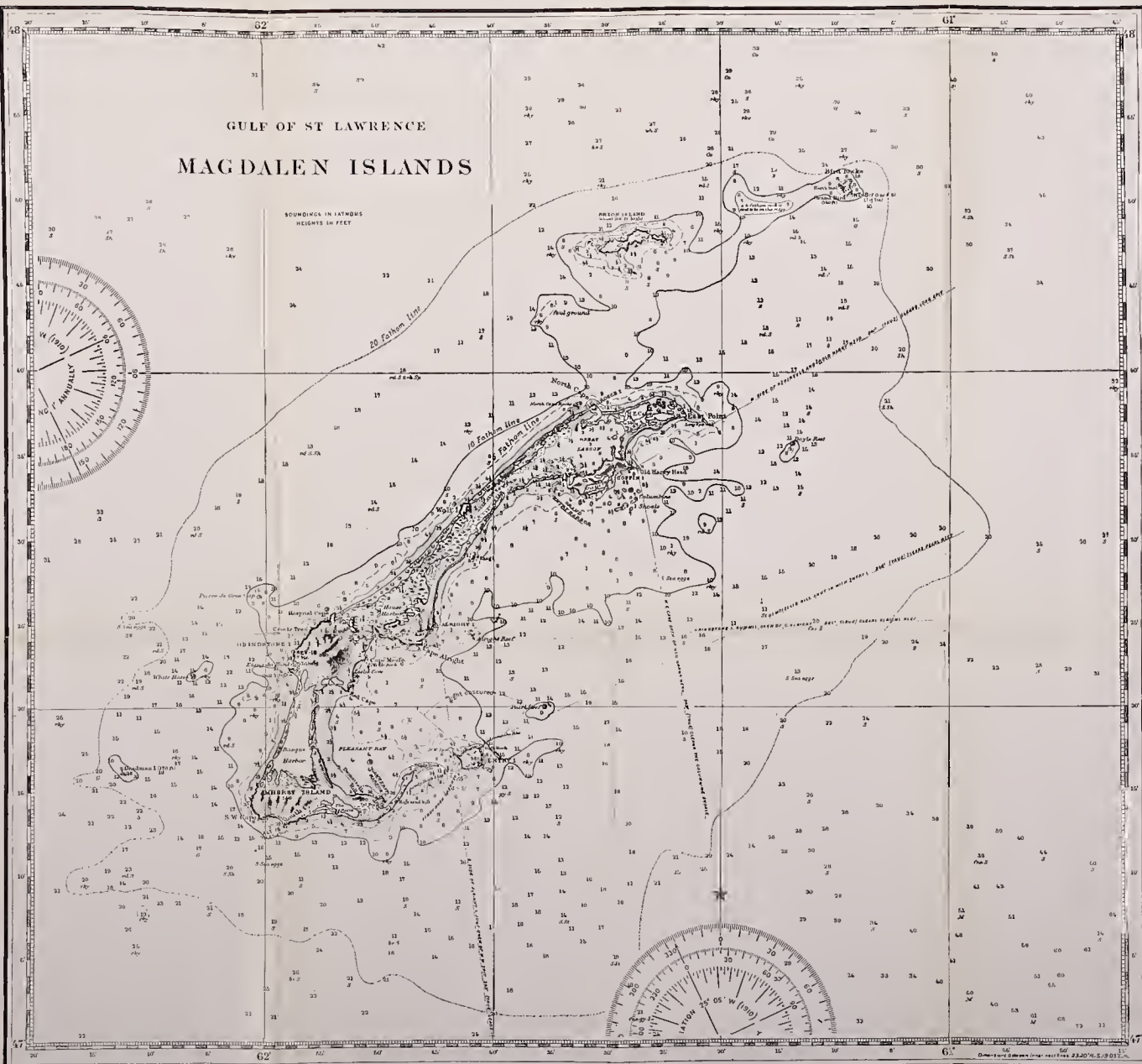
These bits of land which constitute the Magdalens have been saved from total destruction by the slow elevation from the sea in later stages of their history which has given birth to the sands, and extended them over the wasted plateau which the waters themselves have created. I should not say that this was a recent effect, for these great sand bars are often a mile or more across from water to water and the dunes which cap them may be 100 to 150 feet in height, while their mobility is restrained in part by caps of bunch grass and stunted spruce. The islands and their sands are the ruin wrought by the sea; so they in their turn have wrought terrific ruin to sailors and sail from the time the Europeans began to throng the gulf. Their long, low, dark coasts and treacherous bars have lain like a trap for the unwary navigator; and when beating out of his course for the channels at the north or the south, or in times of stress when the northeast or northwest seas were driving against the rocks and sands, hundreds of craft have gone ashore on these unlighted cliffs; the bleaching ribs of dead ships are seen on all the coasts, and tales of shipwreck make up much of the history of the islands.¹

Of the islets that lie off the chain only one — *Deadman's island*, a sarcophagus of rock a few miles west of Amherst — is noteworthy and that for its history and associations. It was gruesomely

¹ Many of the inhabitants are castaways and M. Brassette, the venerable postmaster at Amherst, has told me that within his time there have been, he thinks, not less than five hundred ships, great and small, cast upon these islands.

GULF OF ST LAWRENCE
MAGDALEN ISLANDS

SOUNDINGS IN FATHOMS
HEIGHTS IN FEET



sung by Thomas Moore, was the Isle d'Alezay of Cartier's first voyage (1534) and is the Corps Mort of the French. Of the larger islands at the north *Brion* lies ten miles away from Grosse Isle, a block of rock three miles long with sheer walls on nearly all sides, and the *Bird rocks*, famed for centuries for their myriads of water-fowl, lie twenty miles from Grosse Isle. These and their feathered dwellers, the gannets, murres and puffins, kittiwakes and razor-billed auks, have been the subject of many romantic bird tales, the object of numerous marvelous camera sketches, but the geology of these little rocks is simple and of a piece with that of the other fragments of the plateau. The tragedies of human life on this isolated crag of the Great Bird, where reason has often given away to madness and living has fallen foul of death in the keeping of the light, have not been told to the world.

HISTORY OF THE ISLANDS

It is not to be supposed that such tattered fragments of the earth as these islands could have played any large part in the caravan of human events in the western world. Yet each place has been a factor in the progress of discovery at least, and in this these islands have their share. Their intimate history has never been written and perhaps there is no good reason why it should be. Certainly this is not the place in which to set forth even so much as the writer has been able to bring together from the records of explorations and the journals of the early navigators. So much only as is appropriate to the occasion is here put down.

Jacques Cartier was the first European to see these islands, so far as we know. In his first voyage, that of 1534, his course lay southward from the straits of Belle Isle and he made these rock lands in succession from the north; first the Bird rocks, which he named the *Isles aux Margaulx*, then Brion island, to which he gave the name of the first Admiral of France, Philippe Chabot, Sieur de Brion. Here he went ashore and of it he wrote such a glorious description as to make the reader feel he had found a paradise on earth. Some of the later voyagers applied this name, Brion, to the entire group of islands, but Cartier in his second voyage speaks of crossing over from Brion island, which he revisited, to *Les Araynes*—the sands of Grosse Isle and East point. By this name and its variants the group was set down on many of the earlier charts. The charts of the gulf which date from soon after Cartier's voyages, those of Desliens, 1541, Des-

celiers, 1546, 1550; Champlain, 1609; Mason, 1626, and others, are not altogether reliable historical records but are of interest in showing the growth of ideas concerning the form of the islands, and their changes in name, their years of confusion with the Isle St Jean (Prince Edward Island) and their gradual distinction from it. Indeed few if any of the charts to Champlain's time and later made out the Isle St Jean, 50 miles to the west of the Magdalens. We do not know how soon after Cartier's discovery the Normandy and Breton men got in among these islands, but by the latter part of the 17th century the stories they brought home of the tremendous number of seals and walruses to be had, reached England, and started English expeditions into this quarter. There was a voyage made in 1591, by a skipper unknown, on behalf of M. de la Court, Pré Ravillon and Grand Pré, for the purpose of killing "Morses" for "trainé oyl" (see Hakluyt's *Voyages*, v. 8, p. 150), which of itself indicates previous attempts by the French for the same purpose. Then the English attempts upon the islands began, and George Drake made a passage in 1593, finding the harbors occupied by "Britons of S. Malo and Basques of S. John de Luz." Drake found that "by coming a day after the Fayre" his efforts were put to naught; just as Charles Leigh and Sylvester Wyet, who with Drake were the first Englishmen to sail so far within the gulf, are said on their arrival to have been confronted by two hundred French, who had planted three pieces of ordnance on the beach, and three hundred savages — an opposition which led to a sharp sea fight and seems to have effectually dissuaded further attempts on the part of the English to fasten their hold on this business.

These islands were granted in 1653 by the Company of New France to Nicolas Denys as a part with the vast region stretching from Cape Canso at the south to Cape des Rosiers at the north, and the next year Denys received from the king letters patent as governor and lieutenant general to all this great territory. Even today the Magdalen islands belong to Gaspé county and the Province of Quebec. In those early days land patents in the world of New France were given easily and conflicting claims to the same territory issued from the same source often resulted. So it happened that in 1663 the Company of New France conceded these islands to François Doublet of Honfleur, who was commissioned to establish a colony on the "illès de Brion" for the cod and seal fishery. Doublet was also given per-

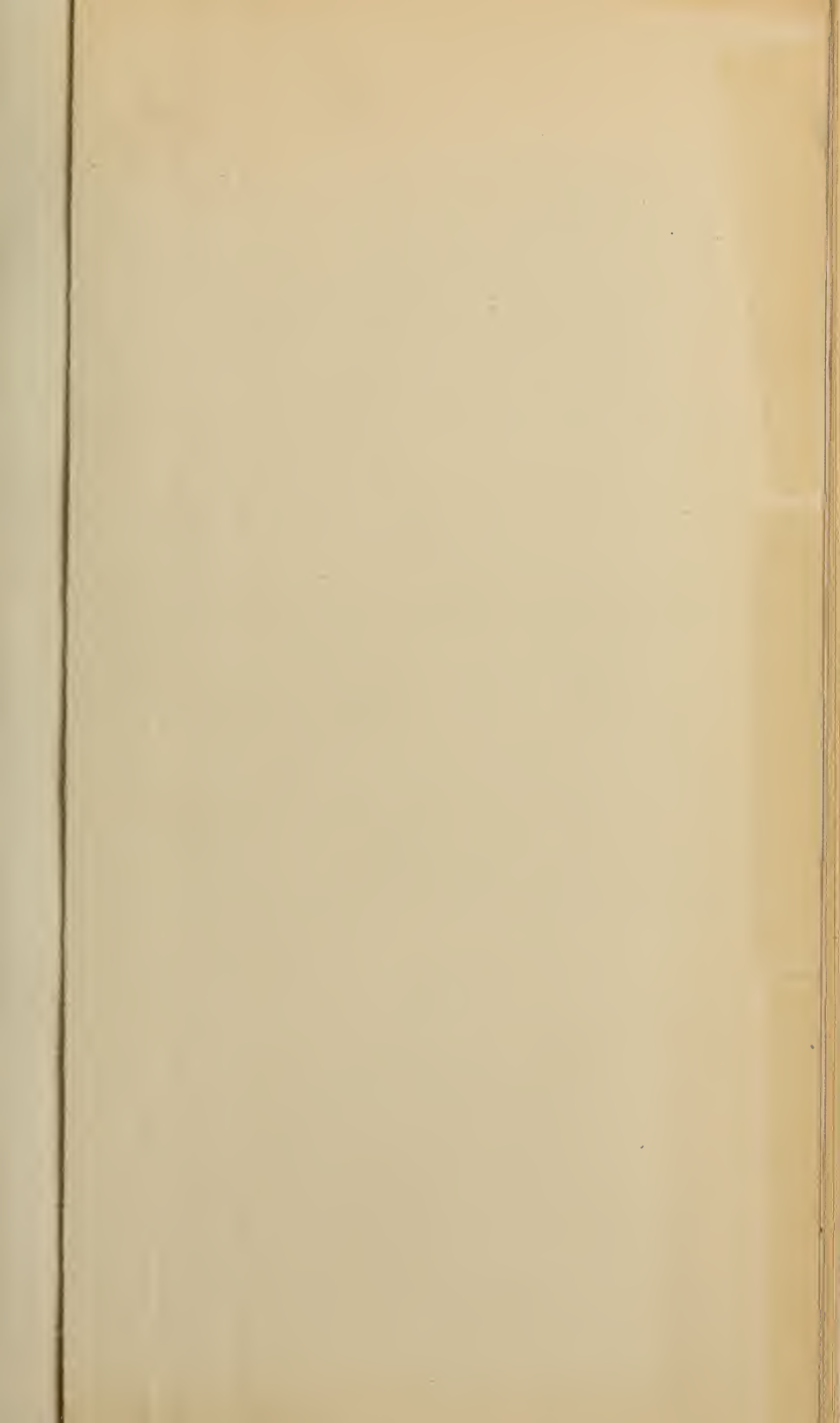
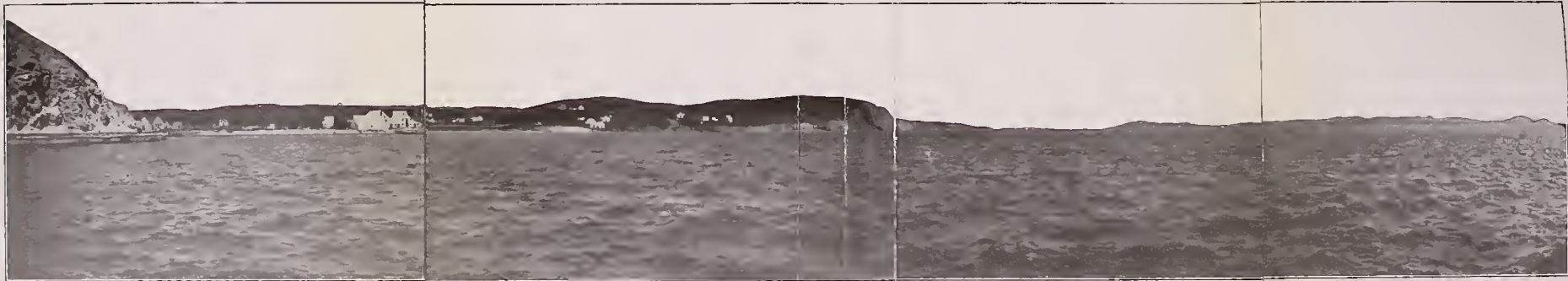


Plate 3



N. T. Clarke phot.

Cape aux Meules, Grindstone island

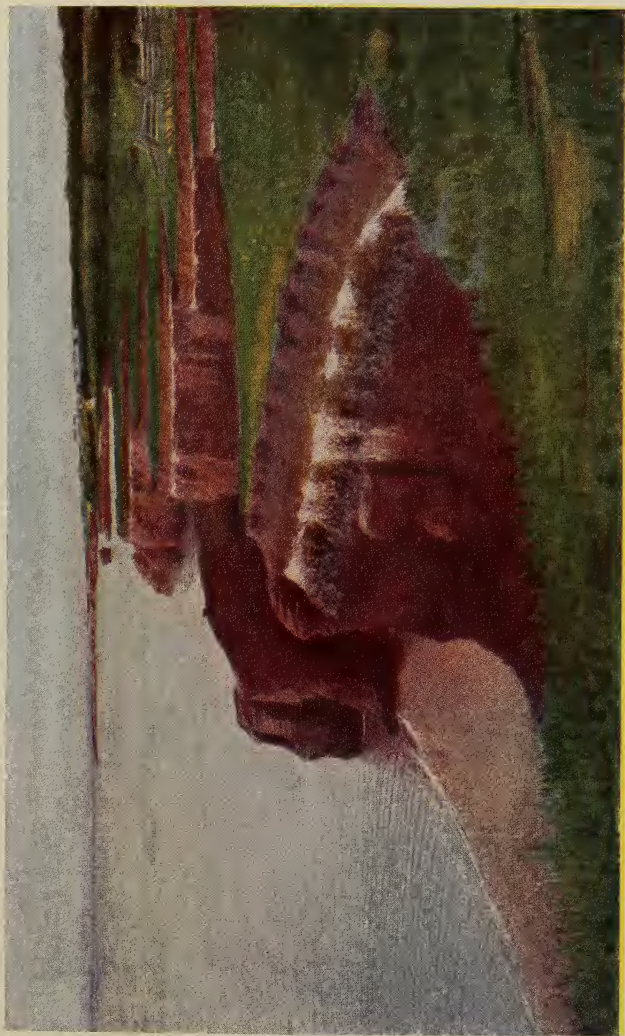
Volcanic gypsum cliffs
Panorama view of the east shore of a part of Grindstone and Alright islands

House harbor

Alright island

Pointe Basse

Plate 4



Magdalen islands. Shore cliffs on Grindstone island in the low lying platform of red Permian sandstone. The line of decolored white sand is everywhere conspicuous and in the foreground a layer of angular diabase pebbles is visible beneath the white sand.

mission to change the name of the islands from Brion to *Madeleine*, which was the name of his wife. So this name has come down to the present, a memorial of conjugal devotion, though Doublet's attempts at settlement failed totally and have been almost forgotten.¹

Like Doublet, Denys failed in his efforts to induce colonization and in 1720 the islands with S. Jean and Miscou, were conceded by letters patent to the Count de Saint-Pierre, Equerry to the Duchess of Orleans. He was commissioned not alone to carry on the fisheries but to cultivate the soil and cut the timber. So far as we know the attempted colonization under this patent effected little and the islands were lost sight of until after the fall of Louisburg and the evacuation by the Acadians of Grand Pré and other settlements when many of the homeless families came here and here their descendants today constitute the majority of the population. In 1763, after the fall of New France, the English government annexed the island to Newfoundland, but by the Quebec Act they were soon after attached to that province where they now belong.

A new era in their history, however, began in 1798, when they were granted by George III under letters patent to Admiral Isaac Coffin, in recognition of his service during the American war and the new proprietor established there a feudal system of land tenure which has remained close to the present day as the last flickering expression of medievalism in the English lands of the western world. Sir Isaac Coffin required the occupants of the islands to take titles in the nature of perpetual leases at an irredeemable rent or emphyteutic leases. The islands cover nearly 100,000 acres and at the usual return of 20 cents per acre per year this would have produced a considerable ground rent

¹ They probably would be entirely forgotten if it were not for a short, sharp passage in Denys's *Description Géographique et Historique des Costes d l'Amérique Septentrionale*, 1672, and had not the departmental archives at Rouen afforded in recent years the manuscript journal of Doublet's son, which was edited and printed in 1883 by Brèard, under the title *Journal du Corsaire Jean Doublet de Honfleur*. This is a remarkable story of a free-booter's life in every quarter of the watery globe, beginning with his successful attempt, at the age of seven, to stow himself away aboard his father's ship which came out to the Madeleines in 1663, the experience of the colony there, the return next year to find the colony demoralized, the place abandoned and the venture wholly lost. Only the name of the islands has remained to record in the geography of the place the first attempt at permanent settlement.

but it never proved collectable, and the system resulted in continued contentions between agent and tenant and at times in considerable migrations from the islands.

In later years the attitude of the seigneur has been more lenient, property may now, under specific law, be acquired in fee and the population has grown to nearly 7000 people, chiefly French who occupy the larger islands, Amherst, Grindstone and Alright, while the English communities are on Entry, Coffin and Grosse Isle. A few years ago the seigneurial rights of the Coffin heirs were acquired by the Magdalen Island Development Company, and the feudal land tenure seemed to have at last become extinguished. In their efforts to develop the islands this company erected extensive fish houses and equipped the islands with gasolene boats for the fishing, but these efforts do not seem to have aided the people or the productiveness of the islands and it is understood that the property has never entirely left the possession of the Coffin heirs.¹

¹ A very interesting account of the land tenure on the islands forty years ago was given by Faucher de Saint-Maurice in his *Promenades dans le Golfe Saint-Laurent* (1874, p. 167). This account is not fully pertinent to the existing conditions and must be regarded as slightly colored by the author's sympathetic interest in the Acadians; but it is out of such feudal tenure as is here pictured that the present state of land and freehold has evolved:

With little regard to the right of the first settlers the English Government committed an act of irreparable injustice. It struck a death blow at the development and future of this charming archipelago, which the sailor has picturesquely called *le Royaume du Poisson*. And so ever since that fatal date, August 24, 1708, the inhabitants of the Madeleines, knowing that they could never own their land, have exerted themselves only so much as necessary to make a living and they know only by hearsay the enjoyment of proprietorship and the love of the soil.

So sad a condition of affairs finally aroused the Provincial Government of Quebec. Sixty-six years after the concession of the islands a commission was charged by Parliament with an inquiry into the land tenure of the archipelago. Fifty-two inhabitants of the Madeleines hastened to answer a series of printed questions which were distributed among the people. Some had lived on the islands for twenty-five, thirty-five and forty-five years; others fifty, fifty-five and sixty years. Only one of these, Jean Nelson Arseneau, was born there, and the dean of the residents was Bruno Terriau, who had lived in the group sixty-six years. All declared that they held their lots as tenants by virtue of long leases and their replies made some curious revelations to the Government.

Thus some of the settlers had billets of simple location which gave them the right to take a lease from the proprietor, while others had a lease for ninety-nine years. Those who had held a lease for fifty-two years had the right to make it continue, and holders of a lease during ten years, to exact a permanent lease from the proprietor. The last procedure did not seem very pleasing to the agents of Admiral Coffin and all agreed that it was gradually

Plate 5



Havre Aubert, Amherst island. Mt Gridley in foreground, "Fishtown" (sandbar) in center and Demoiselle hill in distance; Pleasant bay at the right (east) and the "Basin" at the left.



Amherst island. Mt Gridley from the face of Demoiselle hill; English church on the sky line and Entry island in the distance.

Convincing clues to the history of a country are embalmed in its place names. I have here given the principal names on these islands with suggestions as to their origin.

Madeleine
Magdalen } English } Named for Madeleine Doublet, wife of François
Magdalene } Doublet, 1663.
Maudlin — broad French and vulgar English.

Brion
Bryon } on most English maps } This name, applied by Cartier, 1534, to the
Byron } island now bearing it, was often used
by early explorers for the whole group.
It was given in honor of Philippe Chabot,
Sieur de Brion.

disappearing, for whenever the opportunity presented, the agents changed these leases about.

Generally these leases contained clauses which permitted the seigneur of the islands to take over the lands, to take advantage of their improvements and to possess himself, without reimbursement, of the house and buildings if by some ill-luck the tenant could not fulfil the terms of his lease. It was thus that two of the descendants of the oldest settlers of the Madeleines, Louis Baudraut and François Lapierre, were compelled, after many years of hard work and privations, to abandon to Admiral Coffin the land where their ancestors had lived and which their children had improved to the best of their ability.

This is the way in which Fabien Lapierre was not quite stripped of all his possessions. This man having decided in 1863 to explore the north coast of Labrador, left the land he had occupied for twenty-five years to the care of two of his compatriots, Basile Cormier and Emile Morin. They were to hold it on condition of keeping it up, paying the rent and turning it back to him on his return. For the first year everything went well. The agent consented to take the rental from Lapierre's proxies; but after the beginning of the second year he refused their money, took possession of the land, cut the hay, forced open the house and stored it with the crops for winter use, and afterward sold the whole, land and dependencies, to Desiré Giasson. The following year Lapierre returned and claimed his property. In reply Coffin's agent threatened him not to obstruct the cutting of wood and told him if he continued to make trouble, he would chase him off the islands. But finally by his own pleas and the help of his priest, the Abbé Boudreault, the poor man succeeded in recovering a part of his land on the condition of consenting to a new lease which obliged him to pay annually a shilling an acre. The rest of his property remained and is yet in possession of the purchaser Giasson who has claimed legal title to it by the payment of five pounds. It is not difficult to understand the evils which such a régime imposes on the archipelago and some of the inhabitants, shaking off their torpor, have undertaken to test before the Circuit Court of the Madeleines the titles of Admiral Coffin. Some plead the law of limitations, others allege the illegality of the leases and their burdensome tenure, as contrary to the colonization and progress of the islands. The more philosophical state that for nearly a century their forefathers had cultivated these lands in full ownership, while their descendants and legal heirs can occupy them only as tenants; and the more equivocal say that their ancestors never consented to the title of Admiral Coffin. All these complaints accomplished nothing. The court decided in favor of the proprietor and as most always happens the complainants who perhaps had a chance on appeal from this decision were not able, for lack of

- Ramèes }
 Ramea }
 Ramies }
- Champlain applied the name *Ramède-Brion* to the entire group, *Ramède* having reference to the way in which the islands are strung together by bars. The name was in use before Champlain's time as it appears in Fisher's narrative of 1591 and Drake's, 1593: "Called by the Britons of S. Malo the Isle of Ramea."
- Les Araynes }
 I. des Arenos }
 I. des Arenes }
 I. aux Sablons }
 I. aux Sabloens }
 I. Duoron }
- Cartier, in his second voyage, speaks of crossing over from Brion to the sands, "les araynes," meaning the sands of Grosse Isle and southward. The name appears on early charts in the alternative forms given and applied to all the group except Brion and Alezay.
- Entry I. }
 I. de l'Entrèe }
- A very early name, though evidently not Cartier's. It guards the southeastern portal of the group.

money, to go to a higher court. So matters take their course. Apathy and discouragement reign supreme in the islands which only await the coming of a new régime to become a storehouse of abundance. The tenants continue to pay local and school taxes while their lord and master rigorously exacts the annual rental of the lands—rents which are exorbitant compared with those elsewhere. Nevertheless in the midst of this secret discontent, some of the old settlers find a way to be satisfied with their position. Many of them have a hundred acres under cultivation for which they pay annually only five shillings or a quintal of cod. These are the kings of the isles and they are the envy of those about them; for a young settler who wishes to rent the same amount of land uncultivated and unwooded would be obliged to pay twenty cents a year per acre. Fulfilling this condition he becomes a tenant. For a while youth, ambition and love of work let loose their forces. Under his plow the desert becomes fertile fields. The fish help to make good his deficit. He will be able to live comfortably and be happy though only a tenant. But bad times come, the rent is behind; then come the threats of the agents. The demon of expropriation hovers over his little property; nothing remains to the unhappy man but exile or servitude.

It is not surprising that nearly all this population which otherwise might be enterprising and rich live here, half asleep and in poverty. Strangers flee from this nest of feudalism. These vexatious conditions have resulted in a large migration from the islands to Labrador. More than three hundred heads of families have left the islands and established themselves at Kekaska, Natashquan and Esquimaux Point. These departures have weakened the population of the islands. Every year large numbers go to join those that have already left and it looks as though in the near future the islands may become entirely deserted.

The remedy for the condition pictured here has been found in legislation by the Quebec Parliament which enacted a law in 1895 (Statutes of Quebec, 58 Victoria, Cap. XLV) regulating the form of the land tenure, declaring outstanding occupants to be proprietors subject to payment of rentals and insuring the right of redemption of capital. This law seems to have brought a much desired confidence and sense of security to the islanders without detracting from the income of the seigneur, who now being an heir and substitute of the original proprietor, had, it seems, no legal right to alter the form of the first leases. The province has still further alleviated the condition of the islanders by assuring in amendments to the law cited (59

Plate 6



Demoiselle hill, Amherst island



Red sandstones carrying in the upper part, just under the soil and embedded within the sand, an irregular layer of angular diabase pebbles. The sandstones are horizontal, the apparent cross bedding being a secondary structure. Grindstone island

- Amherst I.
I. Aubert
Hâvre Aubert } Gen. William Amherst—a name given by the Coffin patentees. The old French name is Hâvre Aubert and this is the post office name today. Aubert was commissioner for the islands at an early day and the “Hâvre” has reference to the interior lagoon which has been at various times open for small vessels.
- Pleasant bay
Baie au Plaisance } The broad bay on the east coast of Amherst, a deadly anchorage in an easterly gale.
- Cabin cove
L'anse aux Cabanes } On the south shore of Amherst. Has reference to Micmac lodges there at an early day.
- West point
Sou'west point
Sou'west cape } On Amherst.
- Mt Gridley } The little triangle of land at Amherst wharf. Gridley was an American who established the first lobster fishing here about 1763.
- Demoiselle hill } On Amherst. Takes its name from its symmetrical shape which the French thought resembled a maiden's breast, in which respect it is like all the volcanic-gypsum hills on Grindstone, Alright and Entry.
- Basque harbor
Harbor Basque
Hâvre aux Basques } A name dating to the 1600's when the Basques were in possession.
- Grindstone I.
Pierre Meulière
Isle aux Meules
Isle Blanche } The English name translates the French; all are due to the coarse white sandstone which forms the principal headland, Cape Meule.
- Leslie cove } Named for William Leslie, early pioneer of the lobster business, and still there after 40 years' residence. This is the post office name of the eastern part of Grindstone I.
- Red cape, Grindstone I. Its blood-red sandstones.
- Cape le Trou } Grindstone I. Stands on the hydrographic chart but does not seem to be known to the residents.

Vic. Cap. XXXVIII, 1895, and 60 Vic. Cap. XIV, 1897) a repayment to the tenant of one-third the amount necessary to effect the freehold.

While writing this note, I am informed of a new organization, the Eastern Canada Fisheries, Limited, which is reported to have taken over all the assets of the insolvent Magdalen Islands Development Company and which proposes to take full advantage of the great natural wealth of the sea in those islands.

Hospital cape } Grindstone I. The origin is lost both to the French and
 Cap au hopital } English, but the name naturally suggests a wreck and
 } rescue.

Etang du Nord } Grindstone I. Pronounced by the English, *Tantanour*.
 } The *pond* is the north pond of Basque Harbor.

Alright I. } Sailor's term. Not older than the Coffin patent. Either this or
 } Grindstone I. was called Saunders I., by Bayfield or the
 } Coffins.

House harbor } The harbor between Grindstone and Alright. An
 Harbor Maison } ancient term referring to early settlement, probably
 Hâvre aux Maisons } the first on the islands.

Shag I. This is a bird roost and a shag is a cormorant.

Grand Entry } This passage between Alright and Coffin island seems to have
 } been in use from the days of the Basques and Bretons. It
 } was, I believe, the harbor called by Leigh, 1591, Halo-
 } bolina, and was mentioned by Cartier.

Pointe Basse } The steamer landing at Alright—not on chart. (Pointe
 } Basque?)

Coffin I. Named for the proprietor, Sir Isaac Coffin.

Old Harry head, Coffin I. Probably of like date.

Grosse Isle } The Great Island of the Magdalens or the Great Magdalen of a
 } few English writers. One of the smallest of the group but
 } connected by vast sands with all the other land at the north.

North cape } This is the Cap au Dauphin of Cartier, a name still in use
 } among the French.

Bird rocks } The last two are Cartier's names, 1534. The Rocks are
 Isle aux Margots } separated into North or Great Bird (140 acres) and
 Isle aux Margaulx } the Little Birds, two in number.
 Isle aux Oiseaux }

Deadman's I. }
 Corps Mort } Seven miles west of Amherst. Alezay is Cartier's name.
 Alezay }
 Alezai }

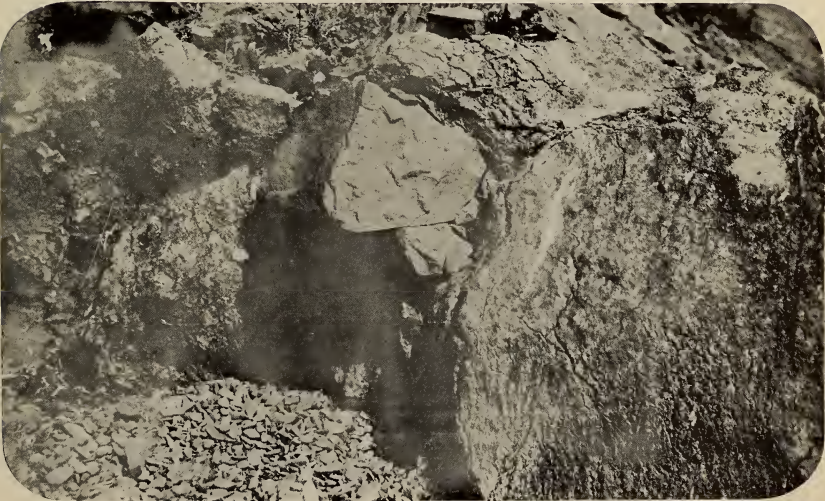
TOPOGRAPHY AND GEOLOGY

Surface modeling. Though the islands are not commanding in bold contrasts of contour, their scenery is inviting and unusual. Rock platforms of dark purple-red bound the lower levels of the coast, broken by higher cliffs of volcanics or of gray sandstone where the sea has cut into the rounded hills. The division in the topography is, in respect to cause, threefold: the sands,

Plate 7



A mass of gypsum filled with angular blocks of diabase. Grindstone island.



Block of diabase entirely surrounded by massive gypsum. Grindstone island.

Plate 8



Red sandstone cliffs at Leslie cove, Grindstone island

the rock platforms and the volcanic-gypsum hills. To the first is due, of course, the present outline and extent of the charted islands and in them are to be found brilliant illustrations of the process of deflation — dune building and anchoring, rock etching — and, further, evidence of the slow upward lift of the islands save perhaps at the southeast. By the rock platforms are meant the low flat-topped rock lands which skirt the rounded hills and reach the coast line in level surfaces and low red fronts of 50 feet or so. The hills are all of one type and I propose to speak of them as *demoiselle hills*; rounded, symmetrical, beehive-shaped elevations with grassy surfaces and separated by shallow or deep cauldronlike depressions. They are the ribs of the islands presenting not only higher but much more resistant fronts to the attack of the sea than the soft crumbling platforms of red sandstone. Their height varies from 580 feet, St Lawrence hill on Entry, down to the knolls and knobs on Grindstone and Grosse Isle, some of which are no higher than the dunes upon the beaches.

These many breasted islands proclaim their neglected fertility and trumpet their virgin claims in the unheeding ears of their fisher folks, whose thoughts are only of the sea. It has perhaps still to be demonstrated that the *demoiselle hills* have all a like origin. The *Demoiselle* on the shore of Pleasant bay at Amherst is a volcanic-gypsum knob (and by this term, which I shall endeavor to explain more fully, is meant an association of gypsum with volcanic effusions and debris), those on Grindstone are mostly of the same order, but Cape aux Meules on Grindstone and Pointe Basse on Alright are gray sandstone knobs in which the presence of either volcanics or gypsum has not made itself evident at the surface, whether or not those may lie at the root of them. The general landscape effect of the islands is well shown in the accompanying panorama view, extending from Cape aux Meules on Grindstone (left) northward to the outermost tip of Alright. The tickle into House Harbor enters the middle distance, the rock front at the left is gray sandstone, the hills next north the volcanic-gypsum series traversing Grindstone, and the rounded tops of Alright beyond lie scattered among the half-disclosed gypsum masses.

Rocks. In a broad sense the rocks of the islands are gray, hard, schistose sandstones, sometimes slightly mottled; brilliant purple-red or blood-red soft sandstones; volcanic masses in the form of diabase sheets, accompanied by agglomerations of

tuffs, permeated by thin seams and sheets of gypsum and followed along their faces by enormous gypsum deposits. The rock geology of the islands has received attention only once and then in a careful though brief report made by Mr James Richardson for the Dominion Survey during the summer of 1880, just 30 years ago, and published in the Geological Survey of Canada, report for 1881.¹ Mr Richardson's keen insight into the relations of these rock masses is a noteworthy characteristic of his work, even though he frankly left many questions to be illuminated.

Stratigraphy. The only detailed section of these rocks given by Richardson is taken from the sea front of Amherst island on Pleasant bay and extending along the escarpment of Demoiselle hill. This section of 856 feet (measured) shows that the hard gray and mottled sandstones lie at the bottom and the soft deep-colored red sandstones above. Yet a change of dip between the lower and upper masses suggests a disconformity and necessarily qualifies the assumption of vertical succession. At the base of this whole sedimentary series lies a mass of partly compact but for the most part badly broken volcanics with an extensive deposit of gypseous clay and an agglomeration of both together. This seems to make the base of the section and produces the curves of Demoiselle hill.

This section of the sedimentaries is typical for the islands Grindstone and Alright, where there is opportunity for adequate exposure. Probably the east shore of Grindstone affords a more favorable and longer section than any other as here is a clean coast line from House Harbor at the north to and beyond Red cape at the south. Here it is seen that the red sandstones which cover all the shore section from just south of Cape aux Meules to Red cape, are, as everywhere else, quite horizontal, and they make a broad flat fringe about the rather distant elevated interior. The sea has cut into them like a mouse into a cheese, carving their frontage into marvelous and bewildering zigzags, aisles and obelisks. Following these red beds north to the cape, they pass without evident loss of conformity or continuity into the gray hard sandstones which make the "Meules." This apparent continuity of the soft red and hard gray series is often seen and I am disposed to believe an approximate explanation of it is to be found in the almost invariable presence with the gray sandstones, when elevated into demoiselle hills, of the vol-

¹ Report of a Geological Exploration of the Magdalen Islands, p. 1-11 G.

canic-gypsum masses. I fancy there is little to militate against the conception that these volcanic lavas with their sulfur and other gases have not only indurated the sands and thus made them more resistant to meteoric downwear, but have decolorized them by rendering the iron oxid soluble. On Grosse Isle Head like conditions are exhibited on a small scale, but more effectively on Alright island where all the demoiselles display the hardened gray sandstones.

Shales and limestones are of the rarest occurrence, but where they have been observed the shales, when calcareous, carry fossils. Where the great gypsum deposit of Grindstone, stretching nearly east and west across the island from north of Cape aux Meules, reaches the vicinity of Cape le Trou, there are fossil-bearing brown bituminous limestones with goniatites and pelecypods, lying close against the white outstanding gypsum cliffs. A few fossils have also been found near House Harbor along the gypsum masses exposed on the property of the Widow Arseneau. At Grand Entry I observed lying among the piles of "killicks" on the beach many blocks of gray calcareous shale with fossils in them and inquiry of the fishermen brought me to the outcrop of this rock at Oyster basin on Coffin island. Mr Richardson reported but one locality of fossils, that on the sea face between Cape aux Meules and House Harbor. Those I have obtained at the three localities mentioned, amounting in all to a very considerable quantity of material (10 barrels were brought away from the Oyster basin locality) I have placed in the hands of Dr J. W. Beede, who has very kindly undertaken to examine and report upon them. Their evidence is, of course, ultimately essential to the determination of the geological age of these formations.

Doctor Beede's conclusions indicate that the marine fauna is of early Carbonic age, to be paralleled in horizon with the Mississippic of the interior basin yet with palpable evidence of development in an Atlantic basin isolated from the interior by the appalachian uplift. All the outcrops which have produced this marine fauna lie very clearly at the base of the sedimentary rock series of the islands, beneath the gray and red sandstones. As to the red sandstones there is no reason to assume any lack of continuity with the similar beds of Prince Edward Island. These have commonly passed as "Triassic" rocks and Leidy, Dawson and Dana believed that this age was effectively determined by the discovery in that island of the reptilian remains which were determined as the lower jaw of a dinosaur.

I am informed by Doctors Lull and von Huene that recent study of this fossil shows it to be the lower jaw of the pelycosaur and hence indicative of Permian age.¹

Volcanics. Mr Richardson believed that the volcanic deposits, on Amherst island particularly, lay at the base of the sedimentary series. It may be quite true that the evidence of their transection of the strata is obscure and even such obscure evidence may give way to proof of interbedding. These volcanics are diabases which stand out in nearly vertical posture on the sea cliffs, are highly amygdaloidal, deeply weathered, and complicated with gypsum deposits. In fact the compact beds are accompanied by agglomerations of lava blocks, decomposed tuffs and gypseous clays in very instructive association; wherever they lie in contact with the sandstones the latter are gray and hard, their induration and decoloration extending for considerable distances away from the contact. The apparent alteration of the augite or allied minerals in the diabase to a chloritic condition gives it in many places a vivid green color and its amygdules are found to contain analcite, chabazite, etc., while the crevices and seams carry pyrite, specular hematite and manganite. Sometimes the manganite is in considerable quantity and excavations have been made for it on Grindstone, whence nodules of comparatively large size have been taken. Frank D. Adams made analysis of this manganite in 1881² and found it to contain MnO_2 , 45.61 per cent; water hygroscopic, 0.10 per cent. The hematite also occurs in considerable rather impure masses.

The association of the gypsum with the diabase is most intimate and while the character of the former is discussed separately I shall here refer to the mode of association. In the greater volcanic exposures, as on Grindstone above Cape aux Meules and on the east face of Alright, these vertical dikes make the highest cliffs. Here the accompanying agglomerates of volcanic blocks, the great masses of volcanic debris in the form of tuffs and ashes, have been referred to. On Grindstone the volcanic masses (at least two distinct dikes are present) have a thickness of fully a thousand feet; with them

¹ Doctor Lull has given me the following citations relating to these remains: Leidy. On *Bathygnathus borealis*, an extinct saurian of the New Red sandstone of Prince Edward's Island; Journ. Acad. Nat. Sci. Phila., (2), ii, p. 327-30, pl. XXXIII, 1854.

Cope. Synopsis of the extinct Batrachia, Reptilia, and Aves of North America, 1869, p. 119.

Dana. Manual of Geology, 4th ed., 1896, p. 754, fig. 1180.

Dawson, J. W. Acadian Geology, 1868, p. 119, fig. 29.

Case. Revision of the Pelycosauria of North America, 1907, p. 63.

von Huene. Neues Jahrb. f. Min., etc., Beil.-Bd. 20, 1895, p. 343.

² Chemical Contributions. Rept. Geol. Survey Canada, 1881, p. 18.

Plate 9



Grosse Isle, from the dunes at the north; showing almost the entire island and fishing settlement, with the English church on the hill. The cape points northwest and the gulf lies to the right.



Grosse Isle. Partly overgrown sand dune; height about 150 feet

Plate 10



The beach at Grosse Isle; in the distance the long sand dunes stretching around
North cape

12

17

2

37

1

17

11

10.

are heavy deposits of tough gypseous clays and fine clear cliffs of crystallized gypsum. All through the volcanics are seams and crystallizations of gypsum, permeating the mass through a multitude of crevices so that large blocks of trap lie entirely surrounded by gypsum. Wherever the trap extends the gypsum follows. In the course of this trap dike westward across Grindstone island the surface is broken up into kettle holes and knobs where the gypsum has undergone secondary change, and where it comes out at the western side of the island near Cape le Trou the white gypsum cliffs stand up brilliantly, with diabase on one side and fossiliferous magnesian limestone on the other. Wherever the volcanics are well developed the gypsum appears and seems always to occur in the presence of the volcanics, except on Grosse Isle Head where a small area of gypsum lies in the gray hard sandstones, and the volcanics, if present, are concealed under an overgrown surface. Without attempting to solve the problem of these interesting occurrences it may be said that there is very little lime left in the exposed rocks of the islands — too little by far to indicate an adequate supply for the lime in these masses of gypsum¹ and if the sulfur in the combination has been supplied by the lavas (which seems, in view of the intimate association of the masses, an almost unavoidable inference) it must have found its lime in some deeper source of older rocks.

Gypsum. The open display of this mineral is brilliant. In the sea faces of Grindstone and of Alright and the weathered pinnacles near Cape le Trou, the rock varies in color through white, gray and pink-white into saffron, red and black; most of it is mottled black and white in laminated colors and all is compact and solid. In secondary deposits among the cavities of the lava are sheets of satin spar together with great crystallizations from a foot's length to the size of one's arm. Some desultory efforts were made years ago to find a market for this gypsum but the material was carelessly selected and taken as ballast to Quebec; the attempt was not really a serious one. The natural supplies lie at the water's edge, working would be free and open and transportation by water to Montreal would give a short haulage by rail to manufacturing centers; by water to Pictou, Boston or New York would grade the haulage according to the port. I have had a series of analyses of the gypsum rock made by Dr E. W. Morley which give some clue as to the ability of the material to meet present commercial demands. These

¹ A million tons of gypsum are easily available on the island of Grindstone alone.

samples were taken from the commonest expressions, not necessarily from the purest. Sample 1 is somewhat out of the ordinary and is not an average. Samples 2 and 3 are fair averages of the predominant rock and there remains a very substantial opportunity of acquiring a better grade by selection. These analyses are here appended.

ANALYSES OF GYPSUM FROM GRINDSTONE ISLAND

By E. W. Morley

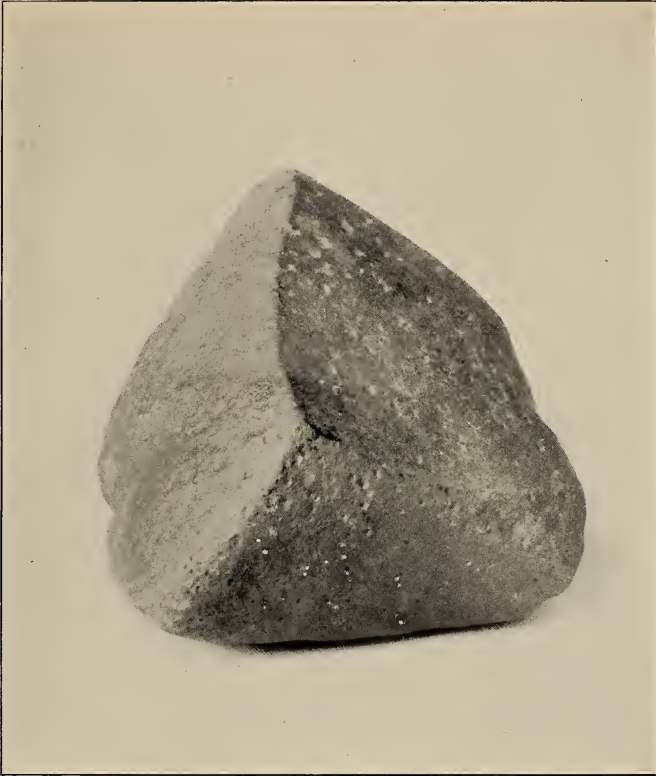
- Sample 1 Compact gray, with red and green mottles
 2 Coarse crystalline, with alternating black and white bands
 3 Darker, with more finely alternating black and white bands

(Each sample has been done in duplicate and the average given)

<i>Sample 1</i>	A	B	Average
Water	14.96	14.90	14.93
Silica	20.93	20.94	20.94
Alumina	5.14	5.07	5.10
Ferric oxid	2.20	2.21	2.21
Calcium carbonate	2.98	3.07	3.02
Magnesium carbonate	4.49	(4.49)	4.49
Calcium sulfate	49.50	49.25	49.37
Chlorine	Trace	Trace	Trace
	<hr/> 100.20	<hr/> 99.93	<hr/> 100.06
	<hr/> <hr/>	<hr/> <hr/>	<hr/> <hr/>
<i>Sample 2</i>	A	B	Average
Water	19.83	19.92	19.87
Silica	0.34	0.37	0.36
Alumina	0.00	0.01	0.01
Ferric oxid	0.36	0.38	0.37
Calcium carbonate	4.29	4.19	4.24
Magnesium carbonate	1.90	1.90	1.90
Calcium sulfate	73.34	73.44	73.39
	<hr/> 100.06	<hr/> 100.21	<hr/> 100.14
	<hr/> <hr/>	<hr/> <hr/>	<hr/> <hr/>
<i>Sample 3</i>	A	B	Average
Water	20.00	20.06	20.03
Silica	0.38	0.43	0.41
Alumina	0.29	0.27	0.28
Ferric oxid	0.32	0.32	0.32
Calcium carbonate	2.04	2.06	2.05
Magnesium carbonate	1.19	1.26	1.22
Calcium sulfate	75.74	75.82	75.78
	<hr/> 99.96	<hr/> 100.22	<hr/> 100.09
	<hr/> <hr/>	<hr/> <hr/>	<hr/> <hr/>

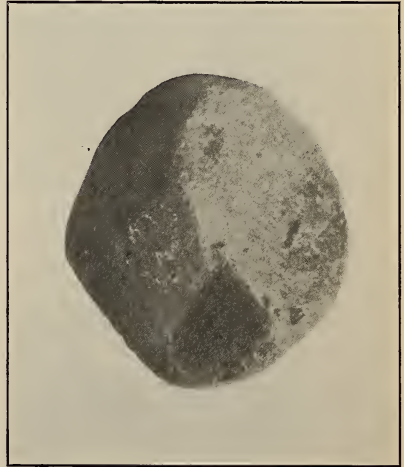
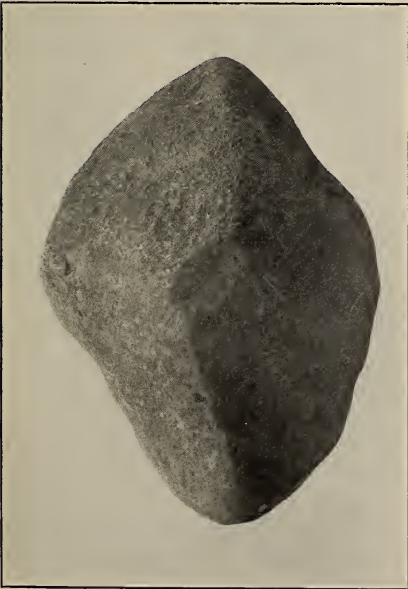


Etched boulder (dreikantner) of banded quartzite. Grosse Isle. Length 7 inches



Sand etched quartzite boulder from the dunes of Grosse Isle. Length six inches

Plate 13



Etched and glazed pebbles of quartzite and sandstone from the red sandstone beds on Grosse Isle head

I have asked Mr David H. Newland, Assistant State Geologist and an accepted expert on gypsum and its commercial values, to express his judgment of the usefulness of these deposits so far as indicated by the analyses given. Mr Newland says:

The sample no. 1, described as "compact gray, with red and green mottles," is an impure material, containing only about 62 per cent of hydrated calcium sulfate or gypsum itself. There seems to be a good deal of free silica or quartz in the sample, and also clay, the latter reaching 10 per cent or a little more. The percentages of iron oxid and carbonates are likewise high as compared with the amounts found in most of the gypsum used for calcined plasters. Rock of the grade indicated by this analysis would have little or no commercial value. Owing to the high iron content the calcined product would undoubtedly be discolored, as it would also be inferior in setting properties by reason of its low percentage of calcium sulfate.

Sample no. 2, coarse crystalline, with alternating black and white bands, according to the analyses contains about 93 per cent of gypsum substance. The chief impurities are lime and magnesia carbonates. These act, of course, as dilutents but would not be detrimental to the use of the material for most purposes. The iron content is fairly low and the burned product should be a good white. The material compares well with the average rock used for the manufacture of calcined plaster in this country, though somewhat inferior to the highest grade of gypsum as represented, for example, in some of the western deposits.

Sample no. 3, darker than no. 2, with finer bands, has about 96 per cent of the hydrated sulfate. It differs from no. 2, chiefly in the smaller percentage of lime carbonate, the difference being made up by the increase in gypsum. The small percentage of alumina, indicative of the presence of clay, is negligible. While the iron is somewhat less in amount than in the preceding sample, there would probably be no essential variance of color between the calcined product of the two grades. The main feature is the increased percentage of the gypsum, which adds by so much to the commercial value of the rock.

Soil. The soil of the islands is essentially residual. The islands have never been subjected to glacial action. One finds on the sand spits and on the lower rock platforms, especially of the northern islands, plenty of ice-borne boulders, for the most part dropped where they lie, and now glazed by the blown sand, but there has been no disturbance of the soil by ice erosion. Hence the softer red rocks, which are largely felspathic, have undergone deep decomposition in place and, under the vegetable mould at the top, the soil extends downward often for 5 or 6 feet carrying all the structure of the

stratification and passing by evidences of less and less decay into the disintegrating layers of the sandstone and thence into the solid rock. A typical section of the soil is given in this sketch, taken from the excavation for Miss Shea's hotel which was being dug at the time of my visit, on Mt Gridley, Amherst island. This includes a section 7' 4" from the surface, there being, from above down:

- (1) 6" of dark brown plant mold
- (2) 8" pure white sand
- (3) 8" deep black mold
- (4) 3' deep red residual soil retaining stratification lines and pebbles (rotted) in place
- (5) 2' 6" reddish passing into yellow soil, running downward into the rotting rock fragments and finally to the solid rock.

White sand. In nearly every soil section on the red rocks the eye is struck by the persistent thin layer of pure white glistening sand not far beneath the surface. It occurs on all the islands, so far as I have visited them. This sand is doubtless the original red sand decolorized by the organic acids which run downward from the vegetable mold, have dissolved the iron oxid and perhaps by transference have given the dark color to the layers which immediately underlie. These highly pure quartz sands are so interesting in their association and in their relation to this residual decomposition that I present here analyses of them made by Dr E. W. Morley, who precedes his report upon them by a statement of his mode of treatment. He says:

I first sifted the two samples, with as little friction as possible, through meshes of 20, 40, 60, 80 and 100 to the linear inch. The table inclosed shows the result. Then the two coarser educts from the white sand were gently pressed with the finger, and the sifting of this sample repeated, with the result shown. The coarser part of the red sand consisted of small fragments of sandstone but the fragments of the white sand were friable and fell into powder finer than 100 to the linear inch. This renders highly probable your suspicion as to the relation of the two sands.

On analyses, the composition was found as in the first and second columns of the table. It may be said that a trace of silica was not separated from the alumina, that potash and soda were not separated and that water was determined simply as loss. In other respects the analyses were as accurate as can be made.

In columns 3 and 4 the analyses have been recomputed as percentages of the weight found for silica. It is seen that every soluble constituent of the white sand is less than in the red sand. As the calcium oxid and sulfuric acid were in both cases equivalent within the errors of determination, they have been entered as calcium sulfate.

Plate 14



Northeast cape, northernmost land of the Magdalens, viewed from within the lagoon at Grosse Isle. This is the Cap au Dauphin of Cartier. 1534



West end of Brion island, seen from the north

Sands from Magdalen islands

	ANALYSES		ANALYSES RECOMPUTED			Mesh of sieve	Red %	White %	Pressed white %
	Red	White	Red	White	Differ- ence				
SiO ₂	82.15	91.66	100.00	100.00	.....	Retained by 20	4.3	5.0	0.7
Fe ₂ O ₃ ...	1.30	0.42	1.58	0.46	1.12	40	3.9	2.2	0.2
FeO....	0.28	0.25	0.33	0.27	0.06	60	3.1	8.2	7.2
Al ₂ O ₃ ...	8.84	4.16	10.76	4.54	6.22	80	1.4	5.4	6.6
CaO....	0.46	0.18	.....	.....	.....	100	3.5	9.2	8.9
MgO....	0.49	0.14	0.60	0.15	0.45	Passed by 100	83.7	69.9	76.3
K ₂ O....	3.17	2.25	3.86	2.45	1.41	.....	.....	.....	.....
SO ₃	0.72	0.22	.....	.....	.....	.....	.....	.....	.....
Water..	2.51	0.65	.....	.....	.....	.....	.....	.....	.....
Ca So ₄..	.....	.....	1.42	0.55	0.87	.....	.....	.....	.....
	99.92	99.93	118.55	108.42	10.13	.....	.....	.....	.....

In these analyses it is quite clear that the red sand differs from the white in the loss of nearly everything soluble by organic and meteoric acids and the inference is fair that the latter are the bleached residue of the former.

Depth of rock decomposition. So profound has been the decay of the red sandstones that it is sometimes difficult to tell where the altered rock ends and the unchanged rock begins. On nearly all sea front exposures, which have naturally not been of long duration, the finger can often penetrate the surface to a considerable depth. On Grosse Isle Head along a new road opened at the side of the lagoon, the red rock has been cut to a depth of several feet from the mold. The red rocks here are interspersed with boulders, some of which are sand-etched (dreikantner). These boulders, when crystalline, hold their substance well, but if of sandstone, as is often the case, they are rotted clear through like their matrix.

On Grindstone island, and particularly along the banks at Leslie cove, there lies between the deoxidized sand and the red sandstone an irregular layer of small angular diabase pebbles forming a gravel which lies with a conspicuous lack of uniformity and constitutes a component part of the sand rock. This layer may be traced all about the southwest cliffs of the island. The pebbles show no marked decay, and are in places accompanied by large boulders. While this layer of angular diabase pebbles lies directly beneath the soil, yet the parts which descend within the substance of the sand rock have no appearance of entering preexisting crevices but are a contemporaneous part of the sandstone itself.¹

¹ On the cliffs of Red cape, Grindstone island, lying on this gravel layer and buried under 6 to 12 inches of plant mold and sod we uncovered the bones of

Deflation. In a region so given over to sands and so exposed to the winds evidences of the destructive power of moving sand are on every hand. The traveling of the dunes does not indeed extend far inland though they have piled up about the few spruce patches that remain on the shores. The most notable effect of sand etching is seen in the angled crystalline boulders. These boulders are ice borne, dropped where they lie by the bergs and floe ice of no recent date. It is very noticeable that these ice-carried blocks are much more abundant in the northern islands, Coffin and Grosse Isle, and that here nearly every example, whether on or in the soil, is a dreikantner, while on the southern islands such blocks are seldom angled by this etching. This fact is naturally explained by the much more exposed situation of the northern islands. Not only are these evidences of recent deflation very apparent, but the adjoining plate shows a group of sand-varnished, angular pebbles taken from several feet down in the decomposed red sandstone at Grosse Isle Head — a testimony that the moving sands were etching pebbles and boulders when these ancient sandstones were being formed, and rather conclusive proof of the continental origin of these rocks.

several walrus, from the skull of one taking a great leaden slug weighing upward of an ounce. On the retreating sea cliffs these bones may be seen projecting here and there from beneath the uncertain soil. These are rather interesting occurrences as it is said that no walrus has been killed in the Magdalens since late in the 18th century. The hunting of the walrus is one of the romantic bits of the early history of the islands. Cartier's enthusiastic account of Brion island and its paradisiacal charms told stories of them which excited the lust of both Bretons and English and it was over the walrus hunting that blood was shed between these peoples. In this pursuit it was the practice to drive the great beasts from the waters or the floe ice up on to the low shore platforms and shoot them at leisure. The bones of the victims are occasionally found at Old Harry point and elsewhere, while the name Sea Cow (vache marine) point still records these resorts. Dr J. A. Allen quotes Professor Packard as stating that the last walrus seen in the gulf was in 1841, when one was killed at St Augustine on the Labrador, but I have heard the report that a few years ago one floated on an ice cake driven under a northeast gale, well up the St Lawrence to beyond Fox river.

The Rev. John Prout, Anglican minister in the islands, kindly put me in the way of securing a very large head taken from the drifted sands at Wolf island and I append here some comparative notes as to its dimensions:

Dr Allen in his measurements of skulls of the Atlantic walrus, *Odobenus rosmarus*, cites from one old male: (1) Canines, length from plane of molars, 330 mm; (2) canines, circumference at base, 197 mm; (3) canines, distance apart at tips, 273 mm. A middle aged male gave the following: (1) 250, (2) 177, (3) 248.

The skull taken from the sands of Wolf island has these measurements thus: (1) 410 mm, (2) 190 mm, (3) 280 mm.

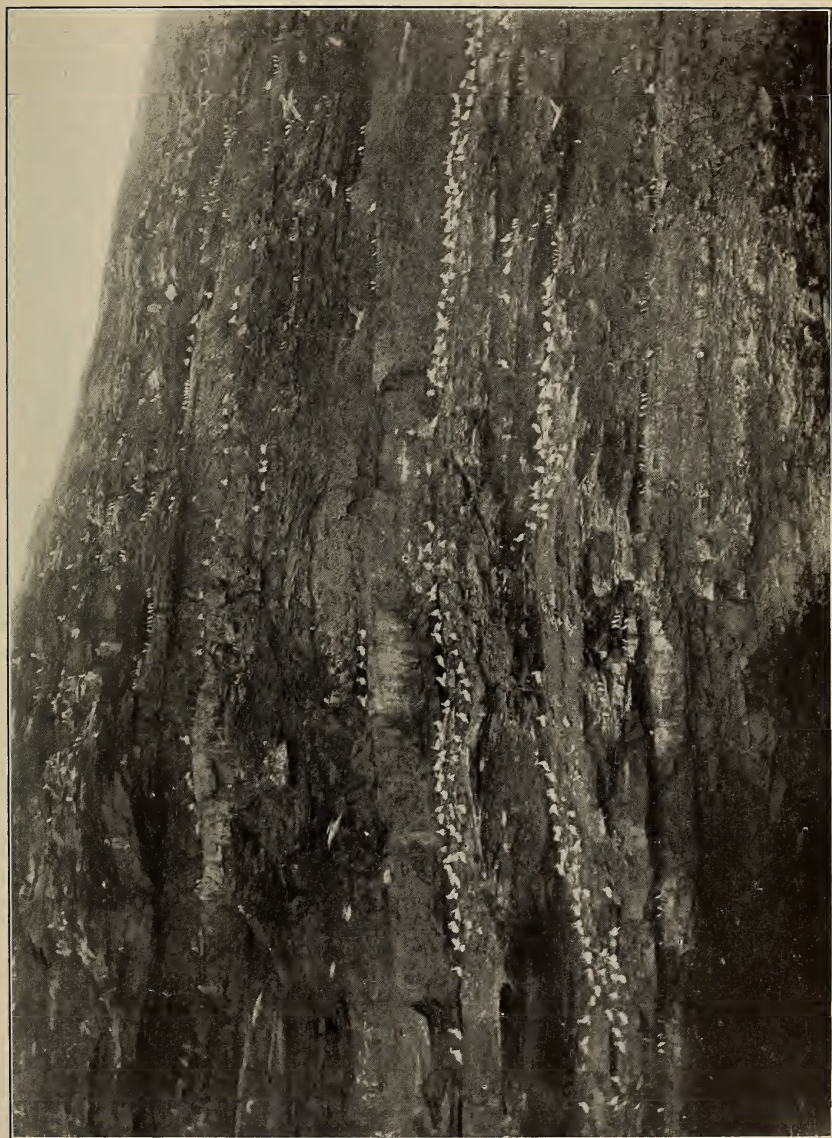
Plate 15



Great Bird rock, from the south; showing light house and accessory buildings



Little Bird rocks, seen from just off the Great Bird



Cliffs of Great Bird rock, from the north. The larger birds are gannets, the smaller murres and puffins.



Sea cliffs of Great Bird rock. Horizontal ledges of sandstone affording nesting places for the gannets and other sea fowl.

Fertility. The deep rich residual soil that overlies the plateaus of the lower land levels has an unbounded fertility and on the knobs and demoiselles where the red sandstone runs into the gray its fertility is carried with it. Today a mere scratching of the surface of the land produces an abundant return of grass, barley and oats and deep plowing is seldom done. Indeed, year after year gives the same fair return of hay without any cultivation. With the simplest mode of planting, potatoes produce enormously and are the common winter food for hogs and cattle. The natural situation of the islands has made them the home of fisherfolk. The lobster, cod, mackerel, herring and seal abound here as they do nowhere else in the gulf and it is these that absorb the energies of the people. Farming only tides over the intervals between the fishing to maintain the live stock and to afford a supply of vegetables. The fertility of the soil seems to have been entirely overlooked as a commercial factor but even recognizing the limitations of the season, it has tremendous possibilities and in the matter of potato cultivation would give large returns at a minimum of cost.

RECENT LITERATURE RELATING TO THE MAGDALEN ISLANDS

S. G. W. Benjamin. The Atlantic Islands as Resorts of Health and Pleasure. Chap. 4, 1878.

James Richardson. Report on the Geological Exploration of the Magdalen Islands. 1881.

S. G. W. Benjamin. The Cruise of the "Alice May." The Century Magazine, April 1884.

A. M. Pope. In and around the Magdalen Islands. Catholic World. 39:369. 1884.

George Patterson. The Magdalen Islands. Nova Scotian Institute of Science. Proc. and Trans. v. 1, pt 1, p. 31-57. 1891.

Anon. Among the Magdalen Islands. Chambers Journal. April 1893, p. 193-95.

Frank Yeigh. Among the Magdalen Islands. Canadian Magazine. October 1908, p. 505.

W. Lacey Amy. The Magdalen Islands. Canadian Magazine. February and March 1911.

For Cartier's route along these islands, 1534, 1535, *see* J. P. Baxter: Jacques Cartier. 1906.

THE CARBONIC FAUNA OF THE MAGDALEN ISLANDS

By J. W. Beede

The Carbonic (Mississippic) fauna of the Magdalen islands, collected by Doctor Clarke, was submitted to the writer for study. Like the earlier Paleozoic faunas of the Gulf of St Lawrence region, these Carbonic faunas are peculiarly interesting and exhibit characters which throw much light on the history and geography of the time and region in which they lived.

In preparing these notes the writer has been under obligation to the authorities of the Peter Redpath Museum, McGill University, for the loan of material from the Dawson collection for comparison with the fauna in hand, and to Dr Stuart Weller for similar aid from the Walker Museum.

History and correlation of the fauna

The only mention heretofore made of this Magdalen islands fauna is in Richardson's report of 1881, to the Canadian Survey. The very few fossils then collected were submitted to Sir William Dawson for identification and his letter in reply is quoted as follows: "I should think the fossils herewith returned indicate, so far as they go, a lower Carboniferous age. The most characteristic is a small specimen of *Bakewellia antiqua*, a very widely distributed species, of which I send one of my own specimens from Windsor for comparison. There is also a *Modiola* or *Cypricardia*, which may be the shell I have called *avonia*, from Windsor, in Nova Scotia; and a little *Cardinia* like *C. mara*, but not determinable. The most abundant species is a *Serpulites* which is very near *S. annulites*, from Nova Scotia, but the state of preservation is so peculiar that I can not be sure of it; the rock altogether resembles one of those black eroded limestones, which, in Nova Scotia, we find in close proximity to the beds of gypsum and which are usually very bare in fossils."

Sir William here drew no conclusion regarding correlation, but it is fair to infer that he supposed the fossils from the Magdalens and Nova Scotia to be intimately related. An inspection of the list of species recorded later in this discussion shows that the relation of these faunas is quite as intimate as Dawson suspected. Indeed it

is so close that the outside correlation of the one may be regarded as equally affecting the other.

Correlation of the Nova Scotia faunas

In the light of these facts the history of the correlation of the Nova Scotia faunas is of peculiar interest here.

Dawson considered their position in the geologic column and their relationships abroad very thoroughly and discussed these points in some detail in his *Acadian Geology*,¹ from which the following summary is extracted:

“The earliest statement as to their age was that of Mr R. Brown, in Hamilton’s ‘Nova Scotia.’ He correctly regarded the limestones of northern Cumberland as lower Carboniferous, on the evidence of their stratigraphical position as underlying the Cumberland coal-field.”

In the central part of the province these rocks were referred to the “New Red Sandstone.” In 1841 Sir William Logan took the beds below the Windsor limestones at Windsor, Nova Scotia, to be Coal Measures and referred the limestones to the Permian. In 1843 Lyell explored the Avon-Pictou region and doubted Logan’s correlation. His views were subsequently confirmed by Dawson and Brown. Davidson found many of the brachiopods to be identical with those of the British “Carboniferous Limestone.” De Koninck confirmed Davidson’s view and correlated them directly with the Carbonic limestones of Visé, Belgium. Nevertheless the red sandstones, marls and pelecypod fauna recalled to their minds the rocks and fauna of the Permian system, the “Bakewellias” playing an important rôle in this respect, and it was also pointed out that they did not suggest the Carbonic of the United States, but the Permian-carbonic, Newberry and Meek both remarking upon it.

In the last edition of *Acadian Geology*, Dawson clearly summarizes his views on the age of the rocks and the peculiarities of the fauna. In number 6 of these statements (p. 284) he says: “It is evident that the marine fauna of the Lower Carboniferous in Nova Scotia more nearly resembles that of Europe than that of the western states. This is no doubt connected with the fact that the Atlantic was probably an unobstructed sea basin as now, while the Appalachians already, in part, separated the deep sea faunas of the Carboniferous seas east and west of them . . .” and again:

“It is a matter of regret to me that I have not had the time fully

¹ Dawson, *Acadian Geology*, p. 278-85. 1878.

to investigate all the facts belonging to this curious question. I would commend it to those who follow me, to whom that which I have been able to do may at least be of use in guiding their researches."

Here we have a clear conception of the scope of the whole problem.

Passing over the intervening time to the present, Schuchert's summary of the correlation will suffice for our purposes. He states:

"The oldest fauna of this series at Windsor includes but few species, and these remind one of Kinderhookian time. In the higher dolomites at Windsor a rich fauna appears that is very different from that in any American Mississippic horizon, and as it is also unlike those of Europe it is difficult to correlate. Seemingly it is of Keokuk time, yet it may be somewhat younger, as Lithostrotion is reported at Pictou, which is not far from Windsor."¹

Characteristics of the fauna

The faunas here discussed were collected from two islands, Grindstone and Coffin, and from five localities, as follows: On Grindstone island: (1) close against the gypsum bluffs not far from Cape le Trou on the west coast, where the rock is a very calcareous, rusty sandstone; (2) near the gypsum bluffs facing the great lagoon, on the property of N. Arseneau—gray calcareous shale as in the locality following. On Coffin island at Oyster basin in a calcareous shale; fragments of this shale have been obtained at Grand Entry landing and at Old Harry point, both on Coffin island, but the former were transported and the latter probably not in place.

In the Grindstone island fauna the most striking feature is the peculiarity of its makeup. The brachiopods are characterized by an abundance of *Productus* belonging to two limited groups, all other groups being absent. There is also a total absence of the *Spirifers*. A few *Dielasmas* are present, a *Pugnax* and an *Orbiculoidea*. The *Pelecypoda* are well represented. Among them are *Liopteria*, *Parallelidon*, *Modiola* and *Aviculopecten* which constitute the majority of the specimens. There are a few undeterminable gastropods, a *Euomphalus* and a few poorly preserved cephalopods.

The *Productus* fauna seems to have developed from two stocks, in an inclosed basin, and the species present fall into two groups, the members of each group being in many ways strikingly similar, but differing sufficiently to permit of careful distinction. This char-

¹ Schuchert. Paleogeography of North America. Geol. Soc. Amer. Bul. p. 551. 1910.

acter, together with the fact that the other groups common to the rocks of this age are absent, is indicative of the isolation of the basin at the time the rocks were deposited. The absence of the Spirifers and of Chonetes, Derbya, Orthothetes and the like all point to the same conclusion.

A general feature of the fauna, especially of the Grindstone island localities, is the extent to which it is dwarfed, the dwarfing being carried even farther than is the case with the Nova Scotian fossils.

Both the Grindstone and Coffin island faunas are related to the "carboniferous limestones" of Nova Scotia, the former the more intimately. The Oyster basin material has 8 species in common with the Nova Scotia rocks and the Cape le Trou material has 20 species. The Cape le Trou and Oyster basin rocks have 6 species in common as listed in this paper. Four species are common to both islands and to the Nova Scotia rocks.

Serpula infinitesima, *Stenopora*? sp., *Hemip-tychina*? *waageni*, *Lingula*, *Strophalosia*, *Aviculopinna*, *Nucula*, *Pleurophorus*?, *Schizodus denysi*, *Martinia glabra*, *Bucanopsis*, *Euphemus*?, and the Ostracoda are confined to the Oyster basin locality and horizon. Five of these species are rather common, several specimens of each and more of some of them occurring in the collection.

The following rather important species, or genera, are represented only in the Cape le Trou collection, the most of them by a number of specimens: *Spirorbis* sp., *Rhombopora exilis*?, *Dielasma sacculus*, *Productus auriculispinus*, *Pugnax*, *Aviculopecten lyelli*, *Liopteria*, *Modiola pooli*, *Parallelidon dawsoni*, *Euomphalus exortivus*?, and most of the cephalopods. The striking feature of these comparisons is the fact that so many of the common species at each locality are restricted to that locality and bed. Though the beds are distinct and of somewhat different composition, yet they are hardly so different as to account for the difference in the faunas contained. There would seem to be a stratigraphic break or a considerable difference in the salinity of the water in which the two beds were laid down. The two localities are about 35 miles apart.

The species in common are: *Beecheria davidsoni*?, *Orbiculoidea limata*, *Productus dawsoni*, its variety *acadicus*, *P. tenuicostiformis*, and *Orthoceras* sp. A.

The peculiarities of the Oyster basin fauna, besides those already discussed, are relatively few, it being a better balanced one than that of Cape le Trou. As to which of these two is the older will probably have to be left to the stratigraphy. In the Windsor (Nova Scotia) section most of the Spiriferacea were confined to the base of the section or were more abundant there than anywhere else. We do not know the range of the species in that section. The fact that *Martinia glabra* occurs here and not at Cape le Trou could be interpreted as evidence for the greater age of the Oyster basin beds. The restricted *Productus* fauna of the latter beds and the absence of *Aviculopecten lyelli* would also point in the same direction. There can be little doubt that the Cape le Trou beds represent beds *d* or *e*, or both, in the Windsor section. From the description given by Dawson¹ it also seems probable that the Oyster basin rocks may represent the base, beds *a*, and *b*, of the Windsor section. The *Nodosinella*, worms etc., together with *Martinia glabra*, would seem to indicate it, but by no means certainly.

The *Nodosinella* from a pebble on the beach of Coffin island at Grand Entry is of peculiar interest in being closely allied to a British species. The *Nuculas* show a fairly close relationship to British species.

The Oyster basin fossils indicate quite as close alliance with the remaining American Mississippic faunas as does the Cape le Trou fauna. One species, *Schizodus cuneus* Hall, is almost certainly specifically identical. Girty records *Martinia glabra*? from the Moorefield shales of Arkansas, and two or three other shells are likely to prove identical on further evidence. None of the Magdalen islands species has been considered identical with the other American species unless the evidence was practically conclusive. This method is hardly practical in studying faunas of the same general basin and succession, but in treating isolated basins it is the only safe one. Aside from the evidence referred to, the affinities of the Oyster basin fauna seem to lie quite as strongly with the Kinderhook as do the affinities of Cape le Trou fossils.

I can not hope to have avoided all British and western European synonymy in describing these fossils, since neither the great mass of the literature nor the time to utilize it has been at my disposal.

¹ *Acadian Geology*, p. 279, 280. 1878.

Correlation with Mississippi basin faunas

A very striking evidence of the isolation of the southern St Lawrence basin at this time is the want of relationship of the fauna of Nova Scotia and the Magdalen islands, with the faunas of similar age in the Mississippi basin. While the number of species common to the two regions is small, yet careful study reveals several species of very similar characters. This is especially true of species of the genera *Edmondia*, *Liopteria*, *Productus*, *Schizodus* etc. Indeed some of them are so similar that were one a little incautious in discriminating characters they might be considered as identical.

Productus tenuicostiformis is sufficiently like *P. tenuicosta* that were it larger and more produced anteriorly the two would readily pass as the same species. *P. dawsoni* is also closely related to *P. laevicosta* and *P. ovata*. *Edmondia* sp. is very closely related to *E. nitida* and to *E. quadrata* from the Kinderhook, but appears to have the beaks more nearly terminal, and is closely related to *E. obliqua* from the Devonian. Relationships nearly as close occur among the other groups and will be occasionally mentioned under the specific descriptions. The general affinities seem to lie with the lower Mississippian. At the same time their rather close relationship to the Devonian pelecypods also makes it apparent that the fauna can not be much farther removed from the Devonian than its relationships with the Mississippi valley faunas would indicate. There seems to be much evidence in the Magdalen islands material to confirm Schuchert's correlation of the beds with the Kinderhook and immediately overlying beds.

THE FAUNA OF CAPE LE TROU, GRINDSTONE ISLAND

These specimens are mostly preserved as casts in a ferruginous magnesian limestone having the appearance of a brownish sandstone.

***Spirorbis* sp.**

Casts too poorly preserved for identification.

***Rhombopora exilis* Dawson?**

Stenopora exilis Dawson. Acad. Geol. p. 287, fig. 85. 1878.

Molds of specimens have the size and form of this species and so far as can be determined, a similar topography.

***Orbiculoidea limata* nov. ?**

(See page 177)

Productus dawsoni nov.

Specimen nearly subquadrate in outline, widest somewhat in front of the middle. The hinge is slightly shorter than the greatest width of the shell, the lateral margins are concave posteriorly and very gently rounded into the evenly curved anterior margin. The shell is quite depressed for a *Productus* and the beak barely projects beyond the hinge, not recurving around it. The ears are nearly flat triangular, carrying many fine spines. The remaining characters are common to the rest of the surface. The surface of the pedicle valve is ornamented with very fine striae which are sharply rounded and narrower than the valleys separating them, somewhat inclined to be wavy, increasing by implantation. The spines of this form seem to be confined to the ears, or nearly so. Posteriorly, there are very slight concentric wrinkles.



Productus dawsoni nov. Pedicle valve, Cape le Trou, Grindstone I.

Dimensions. Length and width of shell 20 mm, length of hinge 15 mm. The specimen figured has a convexity of 4 mm, though it may be very slightly flattened. Fifteen or more striae in 5 mm.

Remarks. This species is very similar to specimens labeled *Productus cora* var. *dawsoni* Hartt, from the Carbonic limestone of Nova Scotia. It is also very closely related to the form figured by De Koninck from the limestone of Visé, Belgium, under the term *P. striatus*.

Productus dawsoni acadicus nov.

This variety resembles *P. dawsoni* in many of its characters but is much more convex, relatively broader and perhaps has a somewhat more protruding beak.

Dimensions. Length, 19.5 mm; width, 21.5 mm; length of hinge, 17.5 mm; convexity, 7 mm, and slightly flattened.



Productus dawsoni var. *acadicus* nov. Cape le Trou, Grindstone I.

Productus arseneau nov.

Cast of small size, subquadrate, wider than long. Ears small, convex, with concentric wrinkles. Hinge-length and transverse diameter of the shell about equal. Lateral margins arcuate; anterior border broadly sinuate, the sinus occupying half its length. The sinus is present over half the length of the pedicle valve. On the surface are about 66 radiating striae, 11 or 12 in 5 mm. They increase in number by implantation and bifurcation, spines sometimes

occurring on the latter points. Posterior part of shell with transverse wrinkles. Diductor muscles attached to 5 or 6 diverging ridges in the pedicle valve; adductor callosities elliptical, deeply depressed on cast.

Remarks. The sinus and the diductor scars and general form of the shell distinguish it from the other species.

Productus laevicostus White?

Productus laevicostus White. Journ. Boston Soc. Nat. Hist. 7:220. 1860.

A specimen apparently identical with this species.

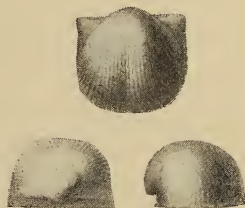
Productus prouti nov.

Shell small, very arcuate from beak to front, except in old specimens when the anterior is nearly straight. Hinge-length slightly exceeding the width of the shell which is narrow for its height. Surface poorly preserved, but one specimen is marked with 9 or 10 striae to 5 mm. On some of the specimens there is no sinus.

Dimensions. Length of shell 12 mm; width, 14 mm; length of hinge about 16 mm; convexity, 10 mm.

Remarks. This species differs from *P. doubleti* in being much more arcuate, more finely striated, and in having a much more highly inflated beak.

As is shown in the illustration, the shell appears to have had a considerable cardinal area and may possibly have possessed teeth. Better preserved material may show it to be a *Productella*.

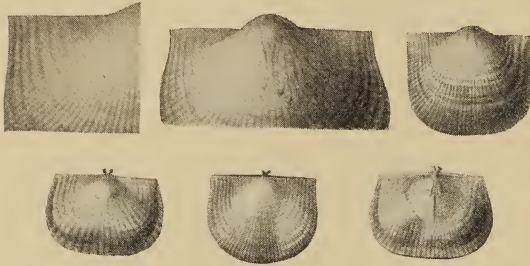


Productus prouti nov.
Cape le Trou, Grindstone I.

Productus tenuicostiformis nov.

Shell subquadrate, gibbous; hinge as long or longer than the transverse diameter of the shell; lateral margins nearly straight from the hinge nearly to the front of the shell where they gently curve into the nearly straight anterior border; beak but slightly produced beyond the hinge, not recurved, very slightly and very broadly inflated. Pedicle valve very strongly arcuate longitudinally and terrace is frequently traceable around the shell at the edge of the visceral chamber; surface sculptured with moderately fine radiating striae about equal in width to the intervening depression, increasing

largely by interpolation in the older part of the shell and by splitting in the anterior portion. Ten or 12 spines are scattered over the sur-



Productus tenuicostiformis nov. Cape le Trou,
Grindstone I.

face of the shell and several crowded on the ears. Posterior part of the valve marked with concentric wrinkles becoming stronger near the ears. The interior of the valve has the muscular attachments

well developed and sharply defined as is revealed in a cast; anterior adductors attached to low indistinct ridges; diductors attached to four or five low bilobate or looped ridges on either side of the adductors. Brachial valve more nearly subquadrate than the pedicle valve, the hinge being about equal to the anterior width of the shell. Valve nearly flat over the visceral region, somewhat depressed in the central region and elevated around it, geniculated at the margin (unless surrounded by a wall). Beginning at the ears a very narrow platform extends outward enlarging as it passes around the sides to the anterior of the valve where it has the width of a millimeter or more. Mesial septum reaching well toward anterior part of valve. Adductor attachments nearly round but showing a tendency to digitate lobation. Cardinal process bilobate at least below, as shown in cast.

Dimensions. Length of shell, 14 mm; width, 18 mm; length of hinge, 19 mm; 9 or 10 striae in 5 mm.

Remarks. The horizontal platform surrounding the visceral area of the brachial valve is of unusual interest since it occupies the position of the murication in Marginifera. No murication is, however, preserved in our specimens, though it could hardly be expected that it would be, and there is little to lead one to suspect that such murication did exist. The generic disposition of the shell is not quite clear. The cardinal process is bilobate, below at least, as in *Productella*, though there seem to be no crural plates to assist in forming sockets for the teeth of the opposite valve and the pedicle valve seems not to have had teeth. The well-defined muscular attachments go with other characters in suggesting its place in *Productus*. The platform, even though not supporting a murication, seems to forecast the subgenus *Marginifera*. Since the more important features are those of *Productus*, it seems advisable to

leave it in that genus until better material is available. This material will be found upon careful search in the Carbonic limestone of Nova Scotia.

Externally, this species resembles *Productus tenuicosta* from the type locality, though it is much smaller and much less produced anteriorly. The full elucidation of the internal characters of both species may show them to be identical, but at present this seems unlikely.

Since this discussion was written a copy of Girty's paper,¹ in which he describes the new subgenus *Diaphragmus*, has come to notice. The character upon which this subgenus is based is exhibited in specimens from the Chesser Group and in a fragmentary specimen figured later from the Moorefield shales. The specimens from older rocks at Cape le Trou and Oyster basin have this feature well developed. Indeed there is some suspicion of its presence in what may be *Strophalosias* from the latter locality. This character seems to have originated as early as the lowest Kinderhook or later Devonian in such shells as *Productus dissimilis* Hall, and reached its fullest development in *Marginifera muricata*, *M. splendens*, and *M. wabashensis*. The presence of the "plate" or "diaphragm" is to be regarded as the inception of shell deposition in the peripheral region of the brachial valve together with its geniculation and later became more and more pronounced resulting in sharp murication of the Pennsylvanian species. Since somewhat similar characters occur in other shells of the Strophomenacea the structure is of doubtful systematic significance at best, and the splitting up of the subgenus *Marginifera* on the basis of the extent of the deposit seems hardly warranted.

Productus doubleti nov.

Cast small, gibbous, strongly arcuate longitudinally, most arcuate near the beak. Beak inflated, broad and full, extending but slightly beyond the hinge. No marked sinus present, central part of shell but slightly flattened in transverse profile; nearly equally arcuate when viewed from side or front. Hinge about equal in length to the greatest anterior width of the shell. Lateral margins slightly arcuate, rounding into the convex front of the shell. On the surface there are 36 coarse radiating striae, those in the central part of the shell being coarser than those on the sides. No



Productus doubleti nov.
Anterior and posterior views of
cast of pedicle valve.
Cape le Trou, Grindstone I.

¹Ann. N. Y. Acad. Sci., XX, 3, II, p. 217, 1910.

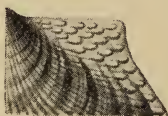
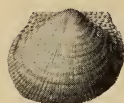
concentric wrinkles over visceral region except a trace of one near the left ear. Muscular impressions weak and not so elaborate as in the preceding species.

Dimensions. Length, 12 mm; width, 16 mm; hinge, probably 13 or 14 mm; 6 striae in 5 mm.

Remarks. This shell resembles to some extent *P. arcuata* Hall but is smaller, almost without reticulations over the visceral chamber and very much less produced anteriorly.

***Productus auriculispinus* nov.**

Shell small, subquadrate in outline, somewhat broader than long. Beak but moderately inflated, the shell rather evenly convex. Hinge short, postlateral margins gently sinuate reaching the hinge nearly at right angles; lateral margins rounding into the evenly convex anterior border. Beak projecting but slightly beyond the hinge and



Productus auriculispinus nov.
Cape le Trou, Grindstone I.

not recurving around it. Fine spines are crowded in rows on the small, triangular, flat ears. Shell covered with fine radiating striae about equal in width to the furrows between them, increasing in number by interpolation or rarely by bifurcation. Crossing these are ill-defined concentric wrinkles, which are much better defined and stronger on the brachial valve.

Dimensions. Length, 13 mm; width, 15 mm; length of hinge, 10 mm; 12 or 13 striae in 5 mm.

Remarks. This species differs from *P. dawsoni* in being relatively broader with shorter hinge and in greater general convexity of the pedicle valve. Specimens nearly related to or perhaps identical with this one were included by Dawson under *Productus cora*. They occur in the limestones at Windsor, Nova Scotia. There is little danger of confusing this species with any other American member of the genus.

***Pugnax magdalena* nov.**

Specimens of moderate size, flattened upon fossilization, apparently rather gibbous and orbicular in outline in uncompressed specimens. Posterior third of shell smooth, anterior two-thirds with fold, sinus and costae; fold decidedly elevated and divided by a median sulcus into two strong, angular costae. There are two or three



Pugnax magdalena nov.
Dorsal and ventral sides.
Cape le Trou, Grindstone I.

costae on the sides of the brachial valve. Pedicle valve gently convex posteriorly, deeply and broadly sinuate in front with single broad, low fold in the center and two or three on the sides of the valve. The cast, though excellently preserved, shows no indication of a mesial septum in the brachial valve.

Dimensions. Length, 8.5 mm; width, 9.5 mm; somewhat modified by flattening.

Remarks. Externally this species seems closely related to *Camarophoria explanata* McChesney, and to *P. globulina* Phillips. It is very doubtful if the shell was ever so globular as the latter, on the form figured by Dawson, and the former has been shown by Weller to be a true *Camarophoria*, possessing a strong mesial septum. Our specimen apparently is without this septum and consequently a true *Pugnax*, like those of the Mountain limestone of Ireland.

***Dielasma sacculus* Martin**



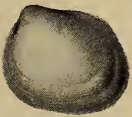
Dielasma sacculus (Martin). Cast of ventral valve. Cape le Trou, Grindstone I.

***Beecheria davidsoni* Hall & Clarke**

A poor cast having a form very suggestive of this species.

***Edmondia intermedia* nov.**

Cast small, obliquely subovate or quadrilateral, only moderately gibbous, beak very near the front of the shell; hinge straight with characteristic slit beneath it; posterior margin nearly straight and oblique above, rounding into the elliptical ventral border which passes with a still gentler curve upward to the hinge. Surface of cast striated on its younger portion with minute, evenly spaced lines parallel with the border; there are also larger growth varices.



Edmondia intermedia nov.
Cast of left valve.
Cape le Trou,
Grindstone I.

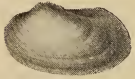
Dimensions. Length, 17 mm; height, 15 mm; length of hinge, about 10 mm.

Remarks. It is not certain that this species may not be *E. nitida* Winchell, and it is also very closely related to *E. quadrata* Weller. It differs from them, apparently, in having its beak more nearly terminal. It is also closely related to *E. obliqua* Hall,

but differs from it in the same respect as well as in the less angular termination of the umbonal ridge and in having the ventral and dorsal margins more nearly parallel.

Edmondia magdalena nov.

Shell small, oblique, very elongate for the genus, nearly twice as long as high. Umbones inflated, protruding above the hinge which is nearly straight and extending about six-tenths the length of the shell. Posterior margin subtruncate, rounding below into the elliptical ventral border which continues in an elliptical curve to the hinge. Beak 2 mm from the anterior end of the hinge. The details of ornamentation are not well shown on the cast, but there are fine, even concentric striae and the usual undulations of the genus.



Edmondia magdalena nov. x2
Cast of left valve.
Cape le Trou
Grindstone I.

Dimensions. Length, 9+mm; height, 5+mm; hinge, 6+mm.

Remarks. This species is similar to *E. hartti* Dawson, but is much smaller and the hinge slopes less steeply anteriorly, and it is slightly more truncated on the posterior end.

Parallelidon hardingi Dawson?

Macrodon hardingi Dawson. *Acadian Geology*, p. 302, fig. 102, 1878.

One small specimen probably belongs to this species. It is on a slab with *Sanguinolites insecta* Daw.

Parallelidon dawsoni nov.

Shell small, subquadrangular, beaks very convex and arched over the cardinal area. Anterior end short, abruptly rounding downward and backward into the gently sinuate ventral margin. Posterior lateral edge evenly and abruptly rounded into the truncated posterior margin which reaches the hinge at a slightly obtuse angle, the anterior and posterior borders being nearly parallel. The length of the hinge is equal to the length of the shell and its direction nearly parallel to the ventral margin. The cast shows fine concentric lines and larger growth varices.



Parallelidon dawsoni nov. Cape le Trou, Grindstone I.



Parallelidon hardingi Dawson. Windsor, N. S.

Dimensions. Length, 13.5 mm; height, 7 mm; beak, 4.5 mm from front.

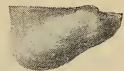
Remarks. In illustrating his species, *P. hardingi*, Dawson used two specimens, one (fig. 102a) a very short, highly gibbous specimen, quite convex beneath the beaks and on the ventral margin

also; and a much longer specimen (fig. 102b) which was less gibbous, with fairly strong depression beneath the beaks producing a corresponding sinuosity in the ventral border. In this genus it seems that these specimens must be regarded as being specifically distinct. The first is taken as the type of his species and the second (2820, in part, Peter Redpath Museum) is regarded as belonging to the species now under discussion. The casts from Grindstone island are smaller and show no trace of radiate markings, nor does the specimen (a cast) just referred to in the Dawson collection. They are regarded as belonging to the same species.

This species is very closely related to *P. obsoletus* Meek and Worthen, from the Coal Measures of the Mississippi valley, but is smaller, has the beak extending more sharply over the cardinal area, and the long teeth parallel to the hinge reach much farther back. It differs from *P. cochlearis* (Winchell) as figured by Weller in that the posterior margin joins the hinge much more nearly at right angles, making the shell less oblique. That shell is probably the nearest relative known of our species.

***Leptodesma borealis* nov.**

Cast of right valve small, aviculiform, with long projection in front of the beak. Hinge about as long as the shell; posterior margin sinuate above but soon becoming gently convex and gradually rounding into the ventral margin. Ventral margin quite sinuate beneath the beak on account of the strong depression in the shell, beyond which the border is convex to the tip of the hinge. The umbonal ridge nearly dies out posteriorly. Surface marked with varices of growth and smaller striae.

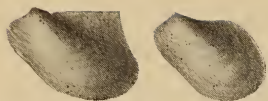


Leptodesma borealis nov. x2.
Cast of right valve.
Cape le Trou,
Grindstone I.

Dimensions. Length of hinge, 8 mm; length of umbonal ridge, 6 mm; beak, 2+mm from front of hinge; height of shell at posterior end of hinge, 4.75 mm; angle of umbonal ridge to hinge about 30°.

***Liopteria dawsoni* nov.**

Cast of left valve small, moderately convex, hinge shorter than the length of the umbonal ridge. Posterior margin sinuate, rather evenly rounded at the termination of the umbonal ridge; ventral margin somewhat sinuate anteriorly but convex around the lobe projecting in front of the beak. The lobe is small and nearly tri-

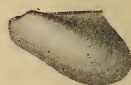


Liopteria dawsoni nov. x 2.
Cape le Trou, Grindstone I.

angular. The weak teeth parallel to the posterior end of the hinge are shown. Varices of growth more widely spaced along the umbonal ridge than elsewhere; the finer lines being about evenly spaced except near the beak.

Dimensions. Length of hinge (from back to posterior end, in this case), 7.5 mm; length of umbonal ridge, 8+mm; height at extremity of hinge, 6+mm; angle of umbonal ridge to hinge, 35°.

Remarks. Though smaller, these specimens seem to be the same species as the "*Bakewellia antiqua*" of the Dawson collection from Gay's river, N. S. Neither our specimens nor the one examined from the Peter Redpath Museum, Dawson's collection, were seen to possess the vertical



Bakewellia antiqua Dawson.
Gay's river, N. S.

cartilage pits of *Bakewellia* though they may possess them. Until they are discovered I am inclined to refer the specimens to the genus *Liopteria*.

Liopteria acadica nov.

Cast of left valve small, aviculiform, well inflated for this genus, hinge shorter than the shell. Beak well elevated; umbonal ridge elevated and very oblique; posterior margin obliquely sinuate, rounding regularly and rapidly into the convex posterior ventral margin; ventral border sinuate beneath the beak; anterior end of shell lobate, the front sloping downward. Cast shows the usual varices and finer striae of growth common to these shells from this locality.



Liopteria acadica
nov. x 1.5.
Cape le Trou, Grindstone I.

Dimensions. Length of hinge, 7 mm; length of umbonal ridge, 11 mm; greatest length of shell, 12 mm; angle of umbonal ridge to hinge, 25°.

Pteronites cf. *latus* McCoy

Pteronites latus McCoy. Carb. Foss. Ireland, p. 81, pl. 13, fig. 7, 1844.

Pteronites latus Hind. Carb. Lam. p. 8, pl. 5, fig. 6, 7, 1901.

Shell small, subtriangular, posterior end probably slightly sinuous. Growth undulations are the only surface marks preserved on the cast. Beak removed from anterior margin. The angle between the hinge and ventral margin is about 35°, the length of the hinge, 11

mm; the height at extremity of hinge, about 7 mm; greatest length of the shell, 12 mm.

Remarks. The ends of our specimen are missing. The shell is very similar in form to Hind's figure of *P. latus* McCoy, and the dimensions are similar, relatively, though our specimen is much smaller. It also seems to be related to shells from the Waverly of Ohio.

Cardinia subquadrata Dawson?

Cardinia subquadrata Dawson. *Acadian Geology*, p. 304, fig. 108, 1878.

A poor cast, the generic and specific determinations doubtful.

Schizodus richardsoni nov.

Cast of valve small, form oblique, characteristic of genus. Beak subtriangular, narrowly inflated; umbonal ridge elevated and gently angular; anterior end of shell short, rapidly curving downward into the elliptical ventral margin which terminates in the angular upward turn at the end of the umbonal ridge. Posterior truncated margin nearly straight and almost vertical, reaching the hinge at an angle of about 120° leaving a relatively large concave triangular area above the umbonal ridge and below the hinge.



Schizodus richardsoni nov.
Cast of left valve.
Cape le Trou, Grindstone I.

Dimensions. Height, 9 mm; length, 11 mm; length umbonal ridge, 10 mm.

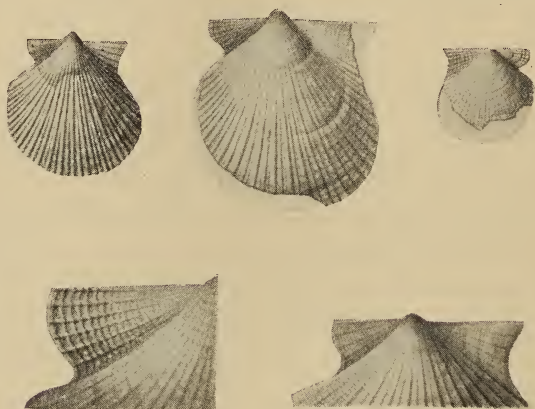
Remarks. This species is much like *S. ellipticus* Hall, from the Hamilton. It seems to differ from it in the front of the shell being shorter and the posterior margin reaching the hinge at a larger angle. The beak is thus made a little more prominent. It differs from *S. iowensis* in having a relatively longer, straighter hinge while the area between the hinge and the umbonal ridge is proportionately larger and the posterior truncation more nearly vertical. Our specimens are closely related to both species.

Aviculopecten lyelli Dawson

Aviculopecten lyelli Dawson. *Acadian Geology*, p. 305, fig. 111a-c, 1878.

Cast of left valve subovate, beak pointed, protruding 1.5 mm beyond the hinge. Shell moderately convex; anterior ear triangular, separated from the shell by a sulcus, rounded at the extremity; margin separated from that of the shell by a deep sharp sinus. Posterior ear somewhat larger, triangular, less sharply separated

from the body of the shell, extremity rather pointed, posterior margin sinuate in joining the shell. Both ears ornamented by radiating striae crossed by striae which, on the anterior ear, are sharp and high, giving it a cancellated appearance. The sculpturing of the shell is somewhat similar to that of the ear. The radiating costae two ranked, the smaller ones interpolated between the larger, 37 in all, crossed by concentric lamellae which are highly vaulted on crossing the ridges as shown in the molds. Ridges rather sharp and about as broad as the furrows except on posterior region where the latter are wider.



Aviculopecten lyelli Dawson. Above, two left valves and one right; below, enlargements of the hinge. Cape le Trou, Grindstone I.

Dimensions. Length of hinge, 12.75 mm; length of shell, 17 mm; height, 19 mm; 6 or 7 striae in 5 mm; angle of beak about 90° .

Remarks. The specimens figured and described here are somewhat undersized. They are closely related to a species from the Knobstone of Indiana but differ in the relative breadth of the ribs, size of the shell, etc. There is a cavity beneath the beaks of our casts, but it is difficult to determine its true character.

Aviculopecten acadicus Hartt?

Cf. Aviculopecten acadicus Hartt. Dawson's Acadian Geology, p. 307, fig. 114, 1878.

Shell small, convex; ears not well developed; beak sharply pointed. Anterior ear sharply separated from the shell, posterior ear not so distinct from it. About 25 radiating costae are shown, separated by wide interspaces and crossed by concentric lines or laminae which are raised on the costae making them appear nodose or the shell reticulated.

Dimensions. Length, 4 mm; height, 4 mm.

Remarks. The slight truncation prevents the shell from being circular as described by Hartt for his specimen from the base of the Windsor limestone. In other respects it agrees very closely with his description and the bit of surface detail figured by him, unless the lamellae are more highly vaulted on our specimen. The species is unrepresented in the Dawson collection in the Peter Redpath Museum and specimens have not been available for comparison.

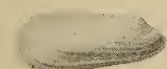


Aviculopecten cf. acadicus Dawson.
Cape le Trou, Grindstone I.

Modiola pooli Dawson?

Cf. Modiola pooli Dawson. *Acadian Geology*, p. 301, fig. 100, 1878.

These specimens, while larger, may be identical with *M. pooli* Dawson. The Shubenacadie specimens seem slender, but if they were increased to the size of these might be identical. The specimen figured is a cast and has been compressed and distorted, producing the effect of a posteriorly placed beak and a depression beneath it which it did not possess.



Modiola pooli
Dawson.
Cape le Trou, Grindstone I.

Sanguinolites insectus Dawson?

Cf. Sanguinolites insecta Dawson. *Acadian Geology*, p. 303, fig. 106, 1878.

The specimen from Grindstone island differs from Dawson's figure in not contracting quite so rapidly toward the beak. Since the beak of Dawson's specimen and of ours are both missing it is impossible to say whether or not they are specifically identical.

Euomphalus exortivus Dawson?

Cf. Euomphalus exortivus Dawson. *Acadian Geology*, p. 309, fig. 118, 1878.

Mold of specimen only, except a flattened section of outer whorl. It is clearly related to the above species, but is much larger, being nearly twice the size.

It differs from *E. sulcifer angulatus* Girty, from the Guadalupian in being larger and having the sulcus more nearly in the center of the whorl.

Gastropoda, 2 species, all minute, too poorly preserved to identify.

Gastropod, a large *Pleurotomaria*-like species, too poorly preserved for identification.

Conularia planicostata Dawson

Conularia planicostata Dawson. Acadian Geology, p. 307, fig. 117, 1878.

Cast of specimen agreeing in all essential characters with Dawson's species.

Conularia sp.

Fragment of another species, too poorly preserved to identify. It is quite slender with about 18 or more ribs in 5 mm. Though poorly preserved, the ribs appear to have been crenulated. Striae coarser and more distant than *C. micronema* Meek, somewhat like *C. sampsoni* Miller, but less obtuse. Striae more distant than in *C. subulata* Hall.

This species may be the variety "novascotica" mentioned by Dawson as named by Hartt, but it is uncertain. It does not seem to belong to any other American species.

Orthoceras sp.

Cavity formerly occupied by specimen.

Endolobus avonensis Dawson?

Cf. Nautilus avonensis Dawson. Acadian Geology, p. 331, fig. 124, 1878.

Endolobus avonensis Hyatt. Proc. Amer. Phil. Soc. 32:536, pl. 8, fig. 36-39, 1895.

Represented by a poor cast, small and distorted. The septa and siphuncle not shown. The dorsoventral diameter of the outer whorl seems relatively large for the Windsor species.

Endolobus? sp.

Several small specimens in concretions which do not admit of specific identification; only camarate portion preserved. Septa extremely convex, suture apparently simple and siphuncle placed very near the venter.

Gastrioceras? sp.

A large shell of which the cast of the living chamber is preserved and some of the outline of what may have been the camarated portion. From the characters shown little can be determined. It has a section corresponding roughly to some of the very large angulate, subnodose members of the genus. Umbilicus is very wide. Transverse diameter 52 mm; about a half the whorl from the aperture 41 mm. Diameter of umbilicus 26 mm.

THE FAUNA OF COFFIN ISLAND

Nodosinella clarkei nov.

Shells long, slender, branching, nodose, usually nearly straight. Test thick, imperforate so far as can be determined. Nodes well defined, quite as wide as long in all specimens sufficiently exposed to show full diameter. Diameter 1 mm, 6 or 7 nodes in 5 mm. Shells apparently monothalamous. In sections cut deep enough to avoid the sharp, keel-like edge of the constriction between chambers no septa are distinctly shown. No indubitable septa seen.

Remarks. This species appears to be related to *N. (Dentalina) priscilla* Dawson,¹ but differs in being 1 mm in diameter instead of a fortieth of an inch, and the nodes are wider than long instead of being considerably longer than wide, and the test is thicker. In all these respects it agrees closely with *N. digitata* Brady. Our specimens differ from material of either species as described and figured, in branching rather liberally. It would seem to be impossible that the great masses of specimens mentioned by Dawson as occurring in the Windsor limestone, even though they were fragmentary, did not include branching forms. None of our specimens show the plane base indicated by Brady for the British species. The shells are 1 mm in diameter while Brady's specimens varied from 1 to 2 mm in diameter.

These tests are uniformly about a millimeter in diameter, except where a segment is enlarged to give off two or more branches, while Brady's species frequently reach a diameter of 2 mm. The tests in thin section under the microscope appear to be nearly homogeneous with a little rusty coloring. No indication of foramina is visible. Considering the very fine calcareous character of the matrix their presence in the tests originally seems improbable. From the state of preservation it seems questionable if they could be referred to the Lagenidae as suggested by Spandel² and others. While a larger amount of material may demonstrate the presence of the characters of this family, I am inclined to leave the specimens in Brady's genus since the ramose character of the species seems incompatible with such shells as *Nodosaria*.



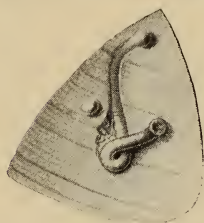
Nodosinella clarkei
nov. x 1.5.
Loose at Grand Entry

¹ op. cit. p. 285.

² Die Foramen. des Deutschen Zechs. etc. p. 6, 1898.

Serpula? infinitesima nov.

Minute, highly contorted, anastomosing tubes which, when highly magnified in cross light, are nodose in appearance owing to rapid contractions and expansions of the shell. Diameter of tubes .1 mm, attached throughout their length to the shell of *Composita dawsoni* (Hall and Clarke) and other species of brachiopods.



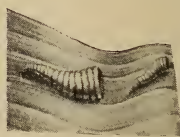
Serpula infinitesima
nov.
Showing (above) the nodose
and contorted form (x 10)
and below the tube partly
buried in the shell (7)

Remarks. This species appears, on other shells, to live quite as largely within the shell as upon it. When it appears at the surface it has the characters mentioned above. It may be straighter within the shell than when partially at the surface. It seems to be partial to the shells of *Martinia glabra*. It is probable that it is not a *Serpula* at all. Several shells of the collection show the effects of this borer though the tests it secretes are gone.

Cornulites? annulatus Dawson?

Cf. Serpulites annulatus Dawson, op. cit. p. 313, fig. 131.

Specimens much smaller than Dawson's and with coarser marks, otherwise typical.



Cornulites? annulatus Dawson?
Oyster basin, Coffin I.

Stenopora? sp.

An immature specimen of the *S. signata* type, or what seems as probable, a form of *Lioclema* with relatively few mesopores. Encrusting form upon *Composita dawsoni* (H. and C.)

Specimens small, encrusting; zoecia varying from elongate where crowded to ovate; acanthopores rather numerous, elevated, largest ones at the angles of the zoecia; mesopores rather numerous, about eight being found in the walls surrounding a single cell, some much larger than others, except at zoecial angles, never in two rows, triangular to subcircular. Five zoecia in 2 mm. Interspaces fairly thick.

One other specimen still smaller than this was found.

Lingula eboria nov.

Shell small, extremely thin, elongate elliptical, twice as long as broad, moderately convex for these shells, especially in umbonal region, posterior end somewhat more narrowly rounded than the anterior but not angulated. Larger growth lines apparently with thicker shell than the intermediate spaces which show very faint concentric marks.

Dimensions. Length, 3.5 mm; width, 1.8 mm. Greatest diameter near the middle of the shell.

Remarks. This shell is very similar to *L. ligea* Hall, from the upper Hamilton, but is less pointed at the beak and more tapering anteriorly and does not appear to be thicker at the margin. This might be governed, however, by the occurrence of the thickening of the shell at the growth stages.

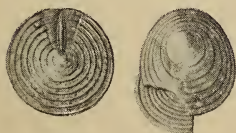
It is less acute posteriorly than the figure of a shell identified as *L. membranacea* by Herrick, but it is very closely related to it, if not identical with it. It is closely related to *L. albipinensis*, as figured and defined by Girty from the Moorefield shales. It is also a close relative of *L. parallela* Phillips.



Lingula eboria nov.
Both valves in opposition.
Oyster basin, Coffin I.

Orbiculoidea limata nov.

Shell small, extremely thin; pedicle valve nearly flat and almost circular, sometimes slightly elongate longitudinally; aperture reaching about half way to the periphery, narrow. Brachial valve with beak moderately elevated and located well toward posterior margin. Surface marked with strong, thick circles of shell between which are small, faint concentric marks.



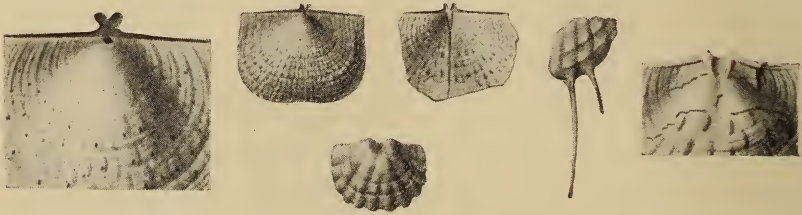
Orbiculoidea limata
nov.
Pedicle valve x 4.
Brachial and pedicle valves
x 3.
Oyster basin, Coffin I.

Dimensions. Length, 5.75 mm; beak, 4 mm from posterior margin.

Strophalosia nebraskensiformis nov.

Shell of medium size, subquadrate. Immediately beneath the beak of the brachial valve, viewed externally, is a minute convexity back of the umbonal concavity of the valve. Valve convex in central portion, and between the ears and the central part two slight concavities lie either side of the anterior median convexity. Interior of valve with a long median septum reaching nearly to the front of the

valve, forked at its union with the cardinal process, inclosing a deep pit immediately above the convexity of the other side of the valve. Process bifid when viewed from below as shown in the impression. One specimen suggests the possibility of a trifold proboscis. The surface is marked by coarse radiating striae which are alternately interrupted giving it the appearance of an ornamentation of elongated, alternating pustules to which occasionally very long, capillary spines were attached. Little is known of the form of the pedicle valve.



Strophalosia nebraskensis nov. In upper row, at left, interiors and exteriors of the valves, with enlargements; below is a very young specimen, pedicle valve ($\times 10$), with scar of attachment and a fragment of a larger shell showing marginal spines, Oyster basin, Coffin I.

One minute young specimen shows the attachment at the beak very clearly as does the beak of another specimen several times as large. In both cases the scar is so small that the specimens must have been attached only by the spines or was free in the adult stages. Surface of this valve ornamented as in the other.

Dimensions. Brachial valve; length, 14 mm; width, 17 mm; length of hinge about 18 mm.

Remarks. The surface ornamentation of this shell is remotely suggestive of *Productus nebraskensis* Owen. It appears, however, to be a true *Strophalosia*, the area of the hinge in the brachial valve being small but distinct. It remotely resembles *S. truncata* Hall of the Devonic.

Beecheria davidsoni Hall & Clarke?

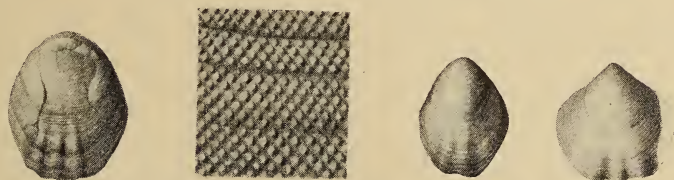
Beecheria davidsoni Hall and Clarke. *Intr. Study Brach.*, pt. 2, pl. 54, fig. 1-3, 1894; *Pal. N. Y.*, 8, pt 2, pl. 79, fig. 33-36, 1895; 14th Ann. Rept. N. Y. State Geol., p. 372, pl. 14, fig. 5-7, 1897.

A few poor specimens which may be referable to this species.

Hemiptychina? waageni nov.

Brachial valve of medium size, quite convex, broad and short, triplicate anteriorly, length exceeding the width, though the specimen is somewhat flattened. Anterior quarter of the shell slightly flattened and occupied by three rounded wide plications. Beak obtuse but sharply defined. Shell very minutely and sometimes

irregularly punctate. Surface plain except for indistinct growth marks. The length and width of the specimen as it lies on the slab is 16.5 mm. The number of plications seems to vary.



He y china ? waageni nov. Two ventra and one dorsal valve, with enlargement of the surface. Oyster basin, Coffin I.

Pedicle valve subovate in outline, longer than broad, convex, widest somewhat in front of the middle. Beak rounded, apparently incurved; postlateral margins but slightly arcuate, passing into the rather strongly rounded antelateral edges; anterior somewhat produced, convex in outline. Little indication of shell having possessed fold or sinus. Six plications occupy the anterior two-thirds of the shell, the four lateral ones being rather indistinct and all of them coarse and broadly rounded. Fine concentric lines mark the surface of the shell together with broader concentric undulations. Interior unknown. Shell symmetrically punctate as in *Dielasma*.

Dimensions. Length, 15.5 mm; width, 13 mm.

Remarks. This shell possesses the peculiar punctate character of *Dielasma*, but in form it is similar to *Hemiptychina* or some specimens of *Notothyris* described by Waagen. The punctations are evidently coarser and more symmetrically arranged than in Waagen's specimens of *Hemiptychina*, but the great disparity of the horizons may account for this, especially if the genus sprang from *Dielasma* or from the same radicle. The globular form of *Dielasmina* is not suggested by our specimen. In this respect our specimen resembles more closely *Hemiptychina*, especially *H. sparsiplicata* Waagen. So long as its internal characters are unknown it may as well rest in this genus as in any. I know of no American Mississippian or Pennsylvanian species resembling it.

Martinia glabra Martin

Spirifera glabra Davidson. Quart. Journ. Geol. Soc. Lond., XIX, p. 170, pl. 9, fig. 9, 10; 1863.

Spirifera glabra Dawson. Quoted by Dawson. Acadian Geology, p. 291, fig. 89; 1868.

Martinia glabra? Girty. U. S. G. S. Bull. 439; p. 70, pl. 9, fig. 9-11.

Specimens of this species are common in the gray shales of Coffin island, at Oyster basin.

It is interesting to note that Girty finds this species, or one practically inseparable from it, in the Moorefield shales of Arkansas.

Composita dawsoni (Hall & Clarke)

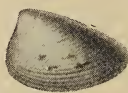
Athyris subtilita Davidson. Quart. Journ. Geol. Soc. Lond. 19, p. 170, pl. 9, fig. 4, 5, (not *A. subtilita* Hall) 1863. Quoted by Dawson, Acad. Geol., p. 290, fig. 88a-c, 1868.

Seminula dawsoni Hall. 13th Ann. Rept. N. Y. State Geol., p. 652, pl. 47, fig. 32-34, 1894; 14th Rept., p. 359, pl. 9, fig. 14-16, 1897.

The specimens referred to this species are not very abundant, are distorted and poorly preserved. It can not be stated that they certainly belong to the species to which they are here referred, though there appears to be little doubt of it.

***Nucula iowensis* White & Whitfield var. *magdalenensis* nov.**

Shell minute, triangular in outline, very ventricose. Beaks nearly terminal posteriorly, little elevated; dorsal border slightly arcuate, sloping forward to the pointed anterior end which rounds abruptly



Nucula iowensis var. *magdalenensis* nov. Cardinal view x 5.
Surface of left valve x 4

into the nearly straight but gently convex ventral margin making an abrupt turn upwards at the posterior extremity. Posterior margin truncated from beaks to ventral extremity. Surface marked by regular concentric crenulated striae separated by depressions of about equal width.

Dimensions. Length, about 4 mm; height, 2.2 mm; convexity, 2 mm.

Remarks. Winchell's description of *N. iowensis* is followed by these remarks:

"The shell appears to be subject to considerable variation at different stages of growth; young specimens often being distinctly triangular, with the posterior end very short, and the basal margin but little arched, while the old specimens are subovate and the posterior end more prolonged. This description of young individuals tallies very closely with the species in hand which may be a variety of Winchell's species. All our specimens are minute.

While resembling the description of the young of Winchell's species, our specimens are very different from the adult forms. His specimens are larger than the largest of ours. The dimensions above given are for the largest specimen.

Our specimens differ from *N. houghtoni* Stevens in being more elongate with straighter ventral margin, as they do from *N. parva* McChesney. It is related to *N. rectangula*

McChesney, but has its beaks less elevated and is relatively longer. It is very closely allied to *N. tumida*, but is more pointed anteriorly. In form it resembles *N. illinoisensis* Worthen, but has strong crenulated surface marks instead of being nearly glabrous. It differs from all of these in its minute size and probably in its surface markings.

***Nucula* sp.**

Shell of moderate size for *Nucula*, beaks scarcely passing above the hinge. Shell inflated below the hinge, mostly broken away. The surface marks consist of very fine, even, closely spaced filiform striae as shown on cast. Specimen originally about 10 mm long, 5-6 mm high and 5.5 mm thick.

***Parallelidon?* sp.**

A shell apparently belonging to this genus, with long straight hinge, elongate posterior border and nearly straight ventral margin so far as can be told from the compressed specimen. The anterior margin appears to pass obliquely forward and then downward, sharply curved from the end of the hinge. Surface marked with fine, regular growth lines and a few very indistinct concentric undulations.

Dimensions. Length, 21.5 mm; height, 7 mm; length of hinge, about 12 mm.

Remarks. This specimen is hardly well enough preserved to identify or describe specifically in this genus where slight variations of form are so vital.

***Schizodus cuneus* Hall?**

Cytherodon (*Schizodus*) *cuneus* Hall. *Palaeontology* N. Y. v. 5, pt 1, Plates and Explanations, pl. 75, fig. 29, 30. 1883.

Schizodus cuneus Hall. *Idem.* p. 458, pl. 75, fig. 29, 30, 1885; Herrick, *Bull. Denison Univ., Ill.*, p. 65, pl. 5, fig. 15, 1888; *Geol. Surv. Ohio*, 7, pl. 21, fig. 15, 1895.

Shell small, ovate-cuneate; length about one-fourth greater than the height; basal margin broadly curved. Post-inferior extremity angular. Posterior margin very obliquely truncate. Cardinal line equal to about half the length of the shell. Anterior end short, contracted just below the beak and regularly rounded below.

Valves gently convex below, becoming gibbous in the middle.

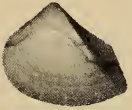
Beaks at about the anterior fourth, moderately prominent. Umbonal slope angular, defined, extending to the post-inferior extremity.

Surface marked by fine fasciculated striae, the remains of which are still preserved in the cast.

The anterior muscular impression is comparatively large and strongly limited on the posterior side. The impression of the strong cardinal tooth is preserved beneath the beak.

Two specimens measure respectively 20 and 22 mm in length, and 15 mm in height.

Remarks. In our specimen it will be noted that the hinge is relatively longer than in the above original description, and, if the specimen represented by figure 30 is excluded, the posterior truncated margin is proportionately shorter. Including this figure, our specimen is intermediate between the two. The beak appears to be quite as prominent in the Coffin island specimen and the shell somewhat smaller.



Schizodus cu-
neus Hall? Left
valve.
Oyster basin, Cof-
fin I.

Schizodus denysi nov.

Shell small, subrhomboidal, rather compressed. Beaks elevated, pointed. Posterior margin very obliquely truncated; postventral extremity angular; ventral border convex throughout, curving more rapidly toward the front; front border convex except for constriction just in front of beak; umbonal ridge angular. The valves are thickest below the beaks which are well anterior. Surface with lines of increment indistinctly preserved on the cast.



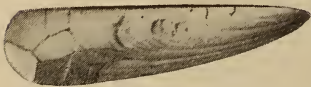
Schizodus denysi nov. Oyster basin, Coffin I.

Dimensions. Length, 12.5 mm; height, 9 mm; length of hinge, 12.5 mm.

Remarks. This shell is related to several Mississippic forms. It is relatively longer than *S. trigonalis*, while the posterior margin is more oblique than in shells of the *S. wheeleri* type. Both the shell and the hinge are longer than those features in *S. curtiformis*.

Aviculopinna egena nov.

Shell small, broad for its length. The hinge appears to be somewhat arcuate. Shell widening rather unevenly along the ventral margin, rather rapidly at first, then more slowly in some specimens. Posterior margin truncatoconvex, possibly slightly sinuate in some specimens. Surface marked by wrinkles of growth which are at right angles to the hinge passing directly downward or a very little



Aviculopinna egena nov.
Oyster basin, Coffin I.

backward as they fall to the central part of the valve when they turn gradually forward becoming more and more nearly parallel with the hinge.

Remarks. This species lacks the sharply raised, evenly spaced, threadlike lines characteristic of the Mississippi valley species. In this respect it resembles the British species, but the posterior margin is truncated at about right angles to the hinge, instead of being very oblique.

One specimen, the largest, appears to have a radiating ridge nearly parallel to the hinge and just below it, but it is probably the hinge of the slightly displaced opposite valve showing on account of the compression of the specimen.

Aviculopecten debertianus Dawson

Aviculopecten debertianus Dawson. *Acadian Geology*, p. 307, fig. 116, 1878.

One specimen, hardly half a valve, reproduces almost perfectly the characters of this species.

Pleurophorus? sp.

A single poorly preserved specimen, rather short and stout for shells of this genus, seems to possess the characteristic ridge of shell which produced the usual depression in the cast in front of the beak.

Cast short, convex, elongate-subquadrate; hinge nearly as long as the shell, straight; posterior end truncated almost at right angles to the hinge and extending to the ventral margin, which is straight, rounding rather gradually into the sharply curved anterior margin. Umbonal region quite convex, beaks incurved, and placed well forward. Umbonal ridge prominent and subangular.

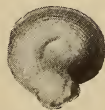
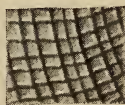
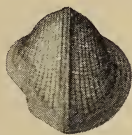
Dimensions. Length, 10 mm; height, 6 mm.

Pelecypoda sp.

Three or four species of minute, poorly preserved pelecypods.

Bucanopsis perelegans White & Whitfield var. *minima* nov.

Shells minute, strongly reticulated. Band with a narrow line on either side, and a thin elevated line along the middle. Surface covered with fine, filiform revolving striae, evenly spaced, 16 or 17 to a millimeter



Bucanopsis perelegans White & Whitfield var. *minima* nov. Shells x5; surface x10.
Oyster basin, Coffin I.

and transverse lines of similar character about 10 to a millimeter, showing a tendency to develop nodes at the intersections with the

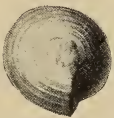
revolving striae. These striae turn backward somewhat on approaching the band. The largest transverse diameter of the shell is 3 mm. Other dimensions unknown.

Remarks. This shell is very closely related to *B. per elegans* from the Kinderhook but differs in its minute size, crowded and evenly spaced revolving and transverse lines. Three specimens observed are all about the same size; some however show the lines somewhat more distant than the specimen described.

Euphemus? sp. Weller

Euphemus? sp. Weller. Trans. St Louis Acad. Sci., 9, 2, p. 40, pl. 5, fig. 10, 11, 1899.

Specimen minute, umbilicated. Dorsal part of the shell compressed, but it appears to have been semiglobular in form. Region of the band is obscured. Six widely separated revolving lines shown on half the shell. No growth lines perceptible. Shell 3.75 mm across, with a thickness of 2.5 mm.



Euphemus? sp.
Weller. Oyster
basin, Coffin I.

Remarks. The outer portion of the last volution is missing but it appears to be the same shell described and figured by Weller from the Vermicular sandstone.

Sphaerodoma? sp.

A poor mold of a large specimen of about four whorls that may belong to the genus. It has a height of about 20 mm, and a diameter of the body whorl of about 15 mm.

Conularia sorrocula nov.

Shell of small size, pyramidal, enlarging at an angle of 20°. Edges of shell round inward, producing an impressed angle; surfaces nearly flat; mesial furrow scarcely impressed; anterior ends of sides arched forward in the center, leaving rather deep angles at their union. Transverse striae arched forward on sides, frequently meeting, sometimes interrupted at the mesial furrow; ten in 5 mm, on the upper part of the shell, more than twice as many near the base, strongly crenulated by the crossing of longitudinal wrinkles which appear coarser and farther apart near the angles; crenulations keel-like, 10 to 13 in 2 mm.

Dimensions. Length, 28 mm; width of valve at aperture 10 mm, incomplete at base.



Conularia sorrocula nov.
Oyster basin,
Coffin I.

Remarks. Differs from *C. newberryi* in having its striae and crenulations more closely spaced and an angle of divergence of 20° instead of 10° .

Orthoceras sp.

Shell small, regularly tapering at an angle of 9° in the uncompressed part. Septa about a millimeter apart near the middle, which is about a fifth the diameter at that place.

Dimensions. Length, 43 mm; width, 8 mm (flattened considerably).

Orthoceras sp.

Fragment of large shell with edge of living chamber. Different species from preceding. Septa about 4 mm apart, somewhat more crowded near living chamber. Length of fragment, 43 mm; width, 15 mm; not showing width of shell.

Ostracoda sp.

One or more species of small ostracods occur in the gray shale of Oyster basin, Coffin island.

TABULAR LIST OF MAGDALEN ISLAND FAUNAS

	Oyster basin, Coffin I.	Cape le Trou, Grindstone I.	Nova Scotia limestones
<i>Nodosinella clarkei</i>	x	.....	.....
<i>Cornulites?</i> <i>annulatus</i>	x	.....	x
<i>Serpula?</i> <i>infinitesima</i>	x	.....	.....
<i>Spirorbis</i> sp. ....	.....	x	?
<i>Rhombopora exilis?</i> .....	.....	?	x
<i>Stenopora?</i> sp.	x	.....	.....
<i>Beecheria davidsoni</i>	?	?	x
<i>Composita dawsoni</i>	x	.....	x
<i>Dielasma sacculus</i>.....	.....	x	x
<i>Hemiptychina?</i> <i>waageni</i>	x	.....	.....
<i>Lingula eboria</i>	x	.....	.....
<i>Martinia glabra</i>	x	.....	x
<i>Orbiculoidea limata</i>	x	?	.....
<i>Productus auriculispinus</i> .....	.....	x	.....
<i>Productus prouti</i> .....	.....	x	.....
<i>Productus dawsoni</i>	x	x	?
<i>Productus dawsoni acadicus</i>	x	x	?
<i>Productus arseneau</i> .....	.....	x	.....
<i>Productus laevicostus?</i>.....	.....	x	.....
<i>Productus doubleti</i> .....	.....	x	.....
<i>Productus tenuicostiformis</i>	?	x	?
<i>Productus</i> sp. A .....	.....	x	.....
<i>Pugnax magdalena</i> .....	.....	x	?

	Oyster basin, Coffin I.	Cape le Trou, Grindstone I.	Nova Scotia limestones
<i>Strophalosia nebraskensiformis</i> ...	x	.....	.....
<i>Aviculopecten acadicus</i> .....	.....	x	x
<i>Aviculopecten debertianus</i>	x	.....	x
<i>Aviculopecten lyelli</i> .....	.....	x	x
<i>Aviculopinna egena</i>	x	.....	.....
<i>Cardinia subquadrata?</i> .....	.....	?	x
<i>Edmondia magdalena</i> .....	.....	x	.....
<i>Edmondia intermedia</i> .....	.....	x	.....
<i>Edmondia</i> sp. A	x	.....	.....
<i>Liopteria acadica</i> .....	.....	x	.....
<i>Liopteria dawsoni</i> .....	.....	x	x
<i>Liopteria</i> sp. ....	.....	x	.....
<i>Leptodesma borealis</i> .....	.....	x	.....
<i>Modiola pooli</i> .....	.....	x	x
<i>Nucula iowensis magdalenensis</i> ...	x	.....	.....
<i>Nucula</i> sp.	x	.....	.....
<i>Parallelidon dawsoni</i> .....	.....	x	x
<i>Parallelidon hardingi?</i> .....	.....	x	x
<i>Parallelidon?</i> sp.	x	.....	.....
Pelecypoda, several small species..	x	.....	.....
<i>Pleurophorus?</i> sp.	x	.....	.....
<i>Pteronites</i> cf. <i>latus</i> .....	.....	x	.....
<i>Sanguinolites insectus?</i> .....	.....	x	x
<i>Schizodus richardsoni</i> .....	.....	x	.....
<i>Schizodus cuneus?</i>	x	.....	.....
<i>Schizodus denysi</i>	x	.....	.....
<i>Bucanopsis perelegans minima</i> ...	x	.....	.....
<i>Euomphalus exortivus?</i> .....	.....	?	x
<i>Euomphalus?</i> sp. (<i>Cephalopod?</i>)..	.....	x	.....
<i>Euphemus?</i> sp.	x	.....	.....
Gastropods, three species .....	.....	x	.....
Gastropod sp. ....	.....	x	.....
<i>Sphaerodoma?</i> sp.	x	.....	.....
<i>Conularia planicostata</i> .....	.....	x	x
<i>Conularia sorrocula</i>	x	.....	.....
<i>Conularia</i> sp. ....	.....	x	?
<i>Endolobus avonensis?</i> .....	.....	x	?
<i>Endolobus?</i> sp. ....	.....	x	.....
<i>Gastrioceras?</i> sp. ....	.....	x	.....
<i>Orthoceras</i> sp. A	?	x	.....
<i>Orthoceras</i> sp. B	x	.....	.....
Ostracoda, one or more species....	x	.....	.....
Total	28	37	.....

EXFOLIATION DOMES IN WARREN COUNTY, NEW YORK

BY W. J. MILLER

INTRODUCTION

While engaged in geological work in Warren county during the past summer the writer was impressed by the fact that the most striking feature of the landscape, especially on the North Creek sheet and certain portions of the Luzerne sheet, is the prevalence of distinct, isolated, domelike, topographic forms which rise hundreds of feet above the comparatively low land of the region. A comparison of the North Creek sheet with all other published Adirondack maps shows that, from the physiographic standpoint, this region is noticeably different from the Adirondacks in general. One would scarcely think of such a very ancient region of comparatively low altitudes as being favorable to a widespread development of exfoliation¹ domes and it is the purpose of this brief paper to call attention to these forms and to show how several factors have conspired to favor their formation. The paper is concerned more especially with the North Creek and Luzerne topographic sheets which the reader is expected to consult.

GENERAL GEOLOGIC FEATURES

The region lies wholly within the Precambrian rock area of the Adirondacks. The oldest rocks are the highly metamorphosed sediments of the Grenville formation. Detailed mapping, now in progress by the writer, shows that the Grenville is very extensively present and that crystalline limestone is unusually prominent in the formation. Next in age come plutonic igneous rocks such as syenite, granitic syenite, and granite porphyry which are clearly intrusive into the Grenville, and all of which are differentiation products from the same cooling magma.

Of the igneous rocks, the syenite is, perhaps, the most abundant and is generally quartzose and hornblendic with a more basic variety carrying a green pyroxene. The rock is medium to coarse grained, greenish gray when fresh and weathers brown. The granitic syenite is highly quartzose and generally carries horn-

¹ The term exfoliation is here employed in the usual sense and means the splitting off of the surface portions of rock masses in large sheets as a result of temperature changes.

blende or biotite or both. It is gray to pink when fresh and weathers light brown. The granite porphyry is biotitic to sometimes hornblendic with large feldspar crystals embedded in a fine to medium-grained matrix. It is gray to pinkish gray when fresh and weathers brown. These igneous rocks are important because they almost invariably constitute the mountain masses of the region. All of these rocks show a distinct gneissoid structure, but are usually very homogeneous in large masses.

Minor intrusions, cutting all of the above masses, occur as dikes of gabbro, pegmatite, and diabase but these have no bearing upon the present discussion.

An important structural feature is the presence of numerous normal faults which have greatly dissected the region.

Finally it should be stated that this portion of the Adirondacks has been vigorously glaciated.

LOCATION AND DESCRIPTION OF TYPICAL DOMES

Since these domelike, topographic forms are so numerous and characteristic of the region, a few only of the more pronounced and easily accessible ones will be mentioned, as follows: Potash mountain, 4 miles north of Luzerne; the Three Sisters, including Pine and Bald mountains on the Luzerne sheet and $3\frac{1}{2}$ miles southwest of Warrensburg; Hackensack mountain at Warrensburg; Kelm, Moon, and Potter mountains respectively $3\frac{1}{2}$ miles north, 3 miles northwest, and 4 miles west-northwest of Warrensburg; Prospect mountain at Chestertown; Mill and Stockton mountains (not named on map) respectively $1\frac{1}{2}$ and 2 miles east of Johnsbury; and Huckleberry and Crane mountains, respectively $3\frac{1}{2}$ and 5 miles south of Johnsbury.

Potash mountain is a remarkable topographic form which is known for miles around as the "Potash Kettle" and it is doubtful if there is a finer example of an exfoliation dome in New York State. The accompanying photograph gives but a poor idea of this steep, domelike mass because it fails to show it in its landscape setting. From base to summit, on the west side, the mountain rises 1100 feet very abruptly and it attains an elevation of nearly 1800 feet above sea level. It presents a striking view toward the east from the train window, between Luzerne and Stony Creek.

The Three Sisters form an interesting group of sharp pointed domes which reach altitudes of 2000 to 2100 feet above the sea or

Plate 1



W. J. Miller, photo.

Potash mountain, four miles north of Luzerne, as viewed from a point on
Gailey hill one mile to the west-southwest. The height of the
dome is 1100 feet.

Plate 2



W. J. Miller, photo.

Potter mountain, four miles west-northwest of Warrensburg, as viewed from a point one mile south-southwest. The height of the dome is 700 feet.

1400 to 1500 feet above the Hudson river, which flows at their base. The domes proper, however, range in height from 400 to 600 feet.

Mill and Stockton mountains deserve special mention because they rise as two great isolated masses above the comparatively low and featureless country in the vicinity of Johnsburg and Wevertown. Each rises abruptly some 600 or 700 feet above the surrounding country and they attain altitudes of 1949 and 1837 feet, respectively, above the sea.

Huckleberry and Crane mountains are completely separated by a narrow rift from 500 to 800 feet deep. The summit of Crane mountain (3254 feet) rises 2000 feet above the immediately surrounding lowlands and it is the highest point in Warren county. The upper 1000 to 1500 feet of this mountain is very steep to almost precipitous on all sides except the north and this great rock dome is a grand sight as viewed from Thurman.

The domes may be classified under three headings according to shape: (1) those with nearly circular bases and which are very symmetrical and almost uniformly steep on all sides as, for example, Potash, Mill, and Stockton mountains and the top of Kelm mountain; (2) those with elliptical bases and represented by nearly concentric elliptical contours to the summit, such as Moon, Birch, No. 9, and Huckleberry mountains: Moon mountain is a good illustration of the broad elliptical type, while Huckleberry mountain is a fine example of the long, narrow, elliptical type; these elliptical forms are the most common and usually have one side very steep due to faulting; (3) those of irregular shape as shown on a large scale by Crane mountain and by many smaller masses.

After climbing many of the domes the writer had been impressed by the almost universal occurrence of exfoliation on a large scale over their surfaces. These mountains are literally peeling or shelling off by the removal of exfoliation sheets of great size, some having been noted as much as 50 to 75 feet across and from 1 to 3 feet thick. Among many other good places to observe this phenomenon are on the west or south sides of Moon, Huckleberry, or Crane mountains. Not infrequently, especially during the fall and spring months, slabs loosen up and go thundering down the mountain sides. Though the igneous rocks are all clearly gneissoid, the exfoliation appears to entirely disregard the direction of the gneissic structure and often great sheets come off at right angles to the foliation.

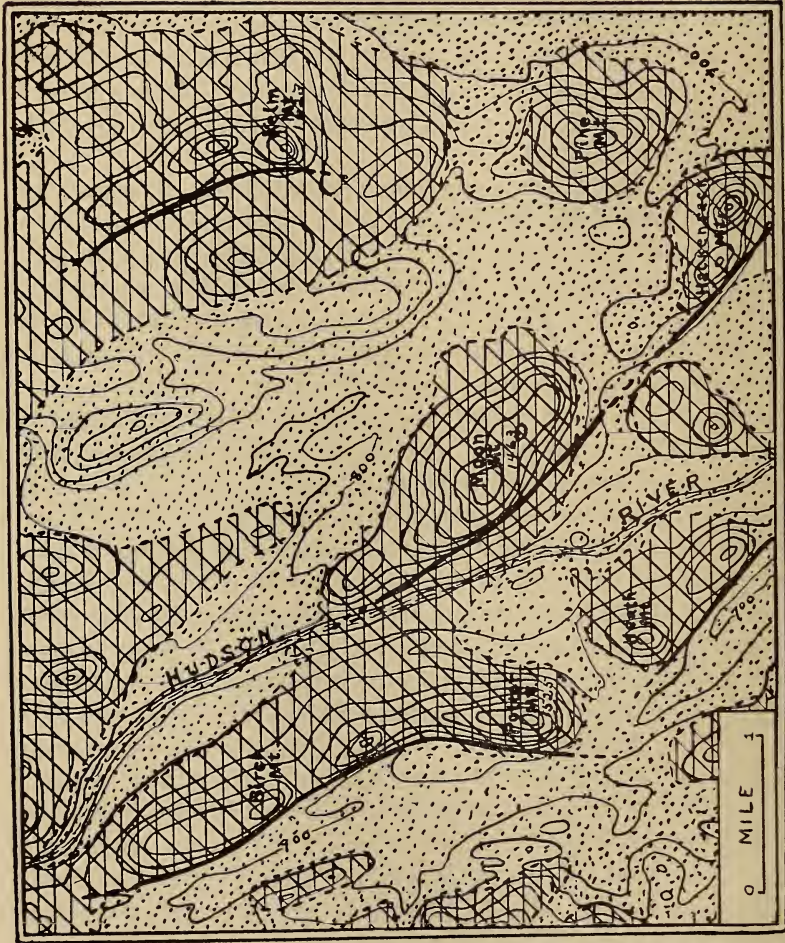


FIG. 1. Geologic and topographic sketch map of the southeastern corner of the North Creek (U. S. G. S.) sheet. Contour interval 100 feet. Dotted areas are Grenville; cross-lined areas are syenite or granite; heavy lines are faults.

FACTORS FAVORING THE FORMATION OF THE DOMES

The very common occurrence of exfoliation domes, in the region under discussion, requires explanation and the writer believes they are due to a combination of factors peculiar to this portion of the southeastern Adirondacks. These factors may be discussed as follows:

1 **Character and distribution of the rocks.** The kind of rock, syenite or granitic syenite, forming most of the typical domes is

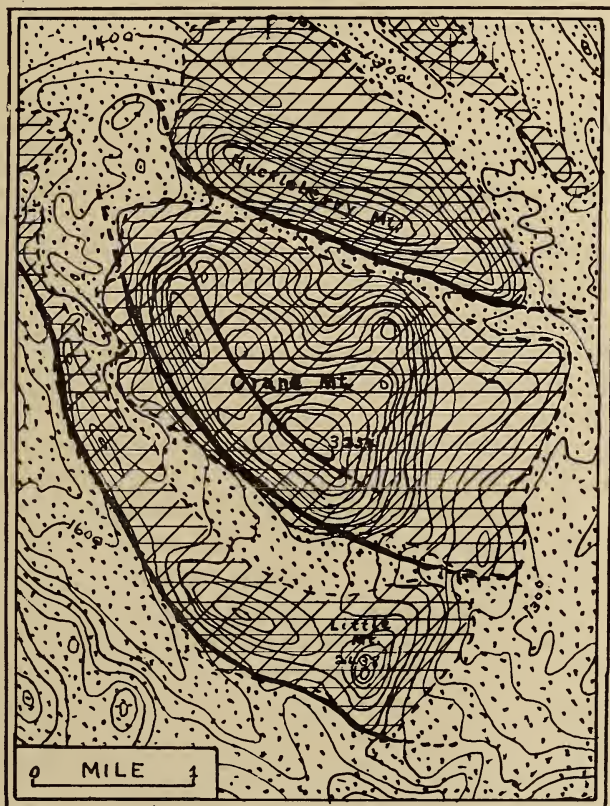


FIG. 2. Geologic and topographic sketch map of the southwestern corner of the North Creek (U. S. G. S.) sheet. Contour interval 100 feet. Conventions same as in figure 1

very favorable because of its medium-grained texture and homogeneity in large masses. The closely associated Grenville rocks, on the other hand, are very variable in composition, generally distinctly banded, and especially rich in limestone, this last feature rendering the Grenville unusually weak and liable to erosion. So far as the mapping has progressed the syenite-granite series and

the Grenville series are about equally extensive. An important feature is the relation of the igneous and sedimentary masses because the igneous rocks, though intrusive as usual, here break through the sediments in numerous small to large separated masses which gives rise to a distinct patchwork effect much more perfectly shown on the geologic map here than on any other Adirondack map so far published. A good idea of this patchwork effect is given by the accompanying detailed geologic maps on which it will be seen that the igneous masses are often nearly or completely surrounded by the Grenville. The protrusion of these very resistant igneous rocks through the weak Grenville is a primary consideration because, as a result of long erosion, the hard igneous masses have stood out as mountains above the worn down Grenville, and thus the way has been prepared for the development of exfoliation domes. The North Creek quadrangle shows an almost perfect adjustment of topography to rock character.

2 Faulting. That the eastern Adirondacks are considerably faulted has been recognized for some years, but, thus far, little attention has been paid to the detailed study and mapping of these faults well within the Precambrian area. As a rule the faults are difficult to locate with any great degree of accuracy and certainty, but in Warren county there is a good opportunity for their study. Frequently the line of contact between the syenite or granite and the Grenville is very regular and sharp, the Grenville seeming to dip under the igneous rock with the latter rising very abruptly and to a great height above the Grenville. Among the best examples of this phenomenon are the southern sides of Huckleberry, Crane, and Little mountains and the western sides of Birch and Potter mountains. There are only two possible explanations of this phenomenon, namely, either that the igneous rocks were intruded in the position which they now occupy or that faulting has occurred. If this is to be explained simply on the basis of intrusion then we are forced to assume a remarkably irregular surface of the newly cooled magma and also that the molten masses, in all of these cases, broke through the Grenville along very straight or regular lines often for miles. Both of these assumptions are entirely out of harmony with well-known observations in other regions. Among the positive evidences for faulting are the frequent presence of sheared or brecciated zones along the lines; the fact that these blocks always show a distinct tilting away from the crests of the scarps; and the well-known faults along Lake Champlain and in the

Mohawk valley, some of which have been definitely traced into the Precambrian area which lies between these regions. As shown on the accompanying maps, this faulting is important for our present consideration because the patchwork effect of the igneous and Grenville rocks has often been either produced or sharply accentuated by this means and many of the finest exhibitions of exfoliation are on the fault-scarp sides of the domes. Huckleberry, Crane, and Little mountains would doubtless not be separated by the narrow Grenville belts except for this faulting. Also it should be stated that a fault almost certainly extends along the western base of Potash mountain with the Grenville sharply faulted against the base of the great dome.

3 Glaciation. It has already been shown by the writer¹ that this region has been subjected to vigorous glaciation, especially the southern portion of the North Creek sheet. Before the Ice Age the lowlands must have been covered with much residual soil while the mountains bore great accumulations of talus material on their sides and especially at their bases. The advancing ice almost completely removed these materials but, more than this, there is strong evidence that, by ice erosion, the Grenville valleys of weak rocks were considerably deepened. If so, the mountains of resistant rock were doubtless bared and rounded off. Except in a few cases of valleys transverse to the direction of ice movement, the outcrops of Grenville and igneous rocks alike are hard and fresh. Most of the loose material now occupying the lowlands is glacial debris of lake or morainic origin. As a result of glaciation the mountains were completely bared of weathered material and vegetation; were often increased in height above the surrounding country; and the fault-scarps were often accentuated in steepness. Thus the preglacial igneous masses were left in a very favorable condition for postglacial exfoliation which is now so prominent. The interesting fact that there is now no great accumulation of talus material around the bases of the mountains is thus readily accounted for.

4 Temperature changes, humidity etc. Chamberlin and Salisbury² state that "the breaking of rock by changes of temperature should be greatest on the bare slopes of isolated elevations of crystalline rock, where the temperature conditions of temperate latitudes prevail, and where the atmosphere is relatively free from moisture. All of these conditions are not often found in one place, but the

¹ Paper read before the Pittsburg (1910) meeting of the Geological Society of America.

² *Geology*, 1:49.

disrupting effects of changing temperatures are best seen where several of them are associated." High altitude is also favorable because in the dry, thin atmosphere the accumulated heat of the day radiates rapidly at night. Of these features favorable to temperature changes and exfoliation the ones notably deficient in Warren county are high altitude and aridity.

Although Warren county is by no means in an arid climate, it is nevertheless interesting to note that its location is in the driest part of New York State except the St Lawrence valley.¹ The average precipitation for the year is only 25 or 30 inches, and hence the comparatively dry atmosphere of this region is important so far as New York State is concerned, because under a dry atmosphere a rock mass heats up more during the day and cools off more during the night, thus favoring exfoliation.

The isolation of the masses of igneous rocks should be mentioned because their better exposure favors greater daily temperature changes.

It should also be stated that changes of 30 to 50 degrees between day and night temperatures in this county are not at all uncommon.

Finally what has been termed the "wedge-work of ice" should be considered. So far as can be learned the greatest movement of exfoliation slabs down the mountain sides is during the fall and spring months and this is probably due to the fact that the cracks in the rock are then pretty well filled with water which expands on freezing and thus wedges off the already loosened slabs.

5 Scanty soil and vegetation. As above stated, the passage of the ice sheet across the region removed all soil, talus, and vegetation from the igneous rock elevations leaving the bare rock surfaces favorable for exfoliation. Though none of the domes are at present entirely free from vegetation there are, nevertheless, many large barren surfaces, and what vegetation does occur is generally scant like small scrub pine, growing out of the cracks in the rocks. The surfaces of the domes are thus at present essentially barren and in this regard favorable for exfoliation.

¹Tarr's Physical Geography of New York State, p. 354.

STUDIES OF SOME EARLY SILURIC PELMATOZOA

BY GEORGE H. HUDSON

In a somewhat caustic criticism of two papers by G. Hambach,¹ the late Dr P. Herbert Carpenter² laid such emphasis on the exhaustive study of the morphology of the nearest living representatives of any fossil form, for one who wishes to understand the latter, as to convey the impression that such study is the only legitimate means to the required end and that "certain American paleontologists and more especially Mr G. Hambach" (loc. cit. p. 277) are innocent of eating of the fruit of this tree of knowledge. No student of the present day is likely to deny the value of exhaustive study in the direction indicated, but in work of this kind it must never be maintained that any one avenue of approach is the only one that is proper or valuable. When Doctor Carpenter says "In order to understand, even with an approximate degree of correctness, extinct groups, such as the Blastids, Merostomata, Dinosauria, and others, a far more extensive acquaintance with the recent members of the same subkingdom is necessary, than for the interpretation of fossil Brachiopoda, sponges, corals, Mollusca and fishes" (loc. cit. p. 277-78), he only emphasizes the fact that the fields in which he insists that a still greater amount of study is needed are just those fields where divergent development and remoteness of relationship have most effectually masked the information sought. The relationship between phyla of the animal kingdom is but one degree more remote than that between such distinct classes as Blastoidea and Holothuroidea and the advice to make "a far more extensive acquaintance" with the morphology of the living dibranchiate Cephalopoda before attempting the restoration of a Brontosaurus would seem highly absurd.

The study of the morphology of living forms is a very essential factor in the establishment of true phylogenies. Even here, however, living forms must receive study from broader and

¹ Contribution to the Anatomy of the Genus *Pentremites*, with Descriptions of New Species. Trans. St Louis Acad. Sci. v. 4, no. 1, 1881, p. 145-60, pl. A and B.

Notes about the Structure and Classification of the *Pentremites*. Trans. St Louis Acad. Sci. v. 4, no. 3, 1884, p. 537-47.

² Further Remarks upon the Morphology of the Blastoidea. Ann. Mag. Nat. Hist. April 1885, p. 277-300.

more varied points of view and the remains of forms that perished ages ago must, in an exceedingly large measure, be included in the reckoning. With such a phylogeny established, the study of ancestral types having living descendants is not a very difficult matter. If, however, the fossil forms are not ancestral but are highly specialized types that left no descendants it is *the morphology of the nearest related ancestral types* that must receive more extensive and intensive study, if we are to understand the modification of such structures as are now presented. There is no short road from any living echinoderm across to the Blastids of the Carbonic era, but the true roads run from the Echinoderm of the present to Cambric or Precambric times and from that remote station, by a branch line, to our desired destination.

So much by the way of preface has seemed necessary to give the author's point of view in the present paper. He is at present quite content to reach a Precambric station in Echinoderm territory by any modern line and hypothetically accept a hypothetical primitive Echinoderm as our best modern students have seen him. From this Precambric station, guided by well-established physical principles, he will reach out into the region of the little known and try to discuss helpfully some curious and interesting structures presented by the relics of a few ancient beings who lost consciousness in Chazy time. The author reserves the right to use any evidence which the morphology of living things may present; he feels that in this remote field the best of present guides may lead him to draw erroneous conclusions, but he sincerely hopes that after the paper has passed the fire of contemporary criticism there will still be left some small measure of fact that may help toward a better understanding of the obscure forms in question.

Echinoderm respiration. Anything tending to interfere with the function of respiration would inevitably lead to greater respiratory effort. If more than one organ or structure shared in the respiratory process, as they do in all Echinoderms, interference with one structure or set of structures would mean increased effort for others, that the physiological balance might be maintained. Prolonged effort would mean abnormal development. The earlier this interference appeared in the life of the individual the more profound would be the modification produced. The ability to modify structure varies with the individual. Variation in direction and degree of such variability

may be said to be congenital and so, without dispute, capable of inheritance. A period of stress during group development not only makes the factor of natural selection more effective but it also adds to the number of avenues of escape tried by the group, or in other words to more active variation and mutation. Without stopping to quarrel over any Lamarckian factor let us state this proposition in different terms. Evolutionary activity in a group of organisms is always greatest during those long periods of time when some particular antagonistic force or forces bear more heavily on the group in question. Cambric or Precambric Pelmatozoa were under just such an increased environmental hostility and their response was the massing and fusion of mineral spicules into strong thecal plates. This very plate formation, however, introduced new factors inimical to respiration and led to exceedingly diversified and specialized types of respiratory structures as early as the age of the Chazy beds or in Ordovician time. It is one purpose of this paper to point out the mechanical effects of increasing mineralization and increasing thecal regularity and show how these factors led to diversity of structure. The subject will be approached largely from the synthetic or deductive side.

Primitive Pelmatozoa were creatures of the sea and respiration could only be accomplished by appropriating oxygen which the sea water had previously taken into solution. This oxygen was largely passed through the epidermis (dermic epithelium) and underlying membranes by osmosis, dissolved by the fluids of various underlying cavities and so circulated through the body. We may designate this as the epidermal supply and the epidermis itself as the principal organ of primitive respiration.

The entire supply could not have been epidermal for these primitive forms swept water into their alimentary canals together with their food, and the amount of water used with the food stream contributed to the oxygen supply. The endoderm was thus made to assume a respiratory function. In later forms water in still larger measure was admitted to a portion of the enteric cavity, or at least to the proctodaeum through the anus. Water entering any portion of the alimentary canal would have its oxygen removed and would receive the products of combustion in return. These alimentary tissues would then come to function in a greater or less degree as respiratory tissues. Such a system might well be distinguished as the alimentary or enteric respiratory system.

A means was also early found whereby water was admitted to the right and left anterior portions of the coelom and from the left anterior coelom was developed the present water vascular system. The amount of water passing in and out of the stone canal was not at first so great as that passing through the enteric cavity and it is doubtful if it ever became so. A still smaller amount might have been drawn into the body through the genital pore or pores. The systems which allow of admission and exit of sea water to any portion of the coelomic cavity may be classed as coelomic respiratory systems.

It has already been stated that the fluid contents of the coelomic cavities, in very primitive forms, received their oxygen supply through the ectoderm and during the development of a thecal armor they maintained such direct osmotic interchange either by means of invaginations of ectoderm or of evaginations of mesoderm. The latter form is abundantly shown in the papulae and podia of living Echinoderms. The respiratory process in such cases depends almost wholly on osmotic interchange through specialized portions of the ectoderm and in a wholly negligible quantity to direct exchange of sea water through the madreporite. Strictly speaking, the respiratory process, whereby the coelomic fluids are given their oxygen and relieved of their wastes, is epidermal and it will here be treated as such. The following tabular form will show these synthetically determined classes and also some probable modifications of them:

TABLE I
MODES OF ECHINODERM RESPIRATION

Epidermal	{ Specialization of plate stereom { Specialization at plate angles and along sutures	{ Invagination { Evagination	{ between regular thecal plates { between thecal plates associated with food grooves Papulae { Podia
Coelomic	{ Gonadial		

Of the two fundamental lines of specialization under epidermal respiration outlined above, it is very clear that the second, that of specialization at plate angles or along sutures, would be vastly the more important. Centers of stereom formation, no matter how open the texture, would offer more resistance to the respiratory process than would their edges or those subtriangular spaces not as yet closed in by the developing plates. The latter would be the line of least resistance and while the less active respiration, which would still take place through the plates themselves, might lead to interesting specializations of plate structure, the more promising field of specialization at plate angles is the only epidermal form which will be considered in this paper.

Synthetically again or by deduction we may postulate two avenues of escape from the inimical influence of plate extension. Either by invagination or evagination of ectodermal tissues, involving in either case some portions of the mesoderm, an increase of respiratory area could be secured and so specialized as to easily maintain the physiological balance. Plate extension would protect and modify invaginated respiratory sacs and soon leave them communicating with the exterior only through small pores or narrow slitlike openings. Either form of external orifice might maintain a position on the suture and, repeating the process as the suture lengthened, give rise to a linear series of such openings, the number being dependent in part on the amount of plate extension. If the external orifice of either form should become surrounded by the stereom of a single plate, the opening would thereafter maintain a fixed distance from the early center of the plate and a repetition of the process would soon more or less fill the plate with such pores or slits and make it appear at first sight as if we were dealing with a case of direct specialization of the plate stereom.

It should also be borne in mind that the extension of plate stereom might divide the external opening and would undoubtedly often do so. If the water exchange was maintained in any degree through ciliary action, any such variation would very materially heighten the value of the sac for respiratory purposes. If both openings should become inclosed by the extending border of one plate we should have a structure very similar to a diplopore. If on the other hand one of the openings should become inclosed by the stereom of one plate and the other opening similarly inclosed by the plate across the suture, the sac would become elongated with the growth of the plates and a structure apparently similar to that presented by some pec-

tinirhombs would be the result. There is still another type that might arise. If the sac pore was divided by the growing corner of the plate, one of the openings might remain on one suture and the other opening on the neighboring suture. Subsequent plate extension might easily convert them into hydrospires and particularly so if one of the openings should be so situated as to receive its water supply by being associated with a covered food groove. The study of cystidean plates will furnish the investigator with an almost endless variety of plate structure and ornamentation, a very large part of which is the outward expression of respiratory structures such as have here been designated.

In those forms which developed recumbent food grooves which in turn were protected by closely fitting covering plates, there would be a mechanical factor tending to promote invagination between certain members of the flooring plates of such a groove. This mechanical factor would be pressure. The water accompanying the minute organisms swept down each brachiole must exert some pressure in the larger food-bearing streams of the food grooves. Invaginations that maintained exits outside of the pseudambulacral area, of the type last outlined, examples of which may be seen in plate 3, figures 1 and 2, would serve a double purpose. The water so drained away would reduce the amount passing through the alimentary canal and give more time for the digestion and absorption of the food content. It would also allow an increase in number of brachioles or an increase in activity and so secure a more abundant food supply. On the other hand all water so drawn through the pseudambulacral invaginations would be used for respiratory purposes and the invaginated sheets would become extended into structures like the hydrospires of *Blastoidocrinus* or perhaps open into each other and form structures like the more specialized hydrospires of the *Blastoidea*.

The respiration of *Blastoidocrinus* is more particularly treated later in this paper and is adequately illustrated. An examination of the matter there presented will serve to make this unique form of respiration more clearly understood. Both forms of ectodermal invagination here outlined serve to admit sea water beneath the test and these forms of respiration may well be spoken of as endothecal.

Evagination of the ectoderm and parietal layer of coelomic epithelium or other membranes at the plate corners would give us structures like those we are familiar with in podia and papulae. Branchial vesicles so formed might come to lie along the sutures or

become surrounded by the stream of plate extension. In such a system the coelomic or other fluids of the body would be carried outside of the theca and effect osmotic interchange with the sea water in that position. This form of respiration might well be designated as exothecal. It would seem that the demands of the environment for a more solid thecal wall should make this latter path the more certain of adoption, for the endothecal system must of necessity mean a larger and, other things equal, a weaker test.

While assuming the attached condition and developing a thecal armor the Pelmatozoa no doubt depended largely on ciliary action for food supply and perhaps in part for respiratory circulation. The manifest advantage of muscular contraction in bringing about such a circulation and the presence of a well-developed muscular system should, however, lead us to expect that a muscular respiratory system would be developed. A more or less rigid thecal wall would offer some very serious obstacles for such a system to overcome and the conditions surrounding such an attempt should be briefly examined.

Take first the simplest possible type of muscular endothecal respiration. We will suppose a single endothecal sac to exist, that this is filled with sea water and that osmotic exchange has reached equilibrium. To continue the respiratory process it becomes necessary to expel this water. With a flexible theca, closed at all other points, this could be accomplished by contracting the whole or any part of the body wall and so reducing its volume by an amount exactly equal to the volume of water to be expelled. With a rigid theca, under similar conditions, the expulsion of this water would be beyond the power of any conceivable muscular organization and this from purely physical and well-understood reasons. With a second opening to the body cavity, be it mouth, anus, genital pore or madreporite, the ejection of the water contained by the sac would be an easy matter if only an exactly equal volume of water were allowed to enter the body by one of the other openings. That the respiration of Echinoderms involves more than one set of organs is well known. What we should note here is that we have a mechanical cause acting in past time that is in itself competent to bring about this very condition.

To insure a better understanding of the problem and to see more clearly some of the relations involved, let us put the matter in a slightly different form. When thecal walls have become solid it is no longer possible to contract any organ save under one of the fol-

lowing conditions. Contraction of one organ is possible if its incompressible contents can be made to pass more or less completely to another organ or body cavity. If the contents of an organ are to be passed outside of the theca it can only be accomplished by admitting an equal volume of sea water to some other organ. To illustrate this reciprocal action, let us suppose that it is desired to draw water through the madreporite. This may be accomplished by reducing the amount in the alimentary canal. If on the other hand it is desired to reduce rapidly the amount of water in the hydro-vascular system, this may be accomplished by its contraction and the passive admission of water to the alimentary canal. The largest external opening possessed by Pelmatozoa is the anus, and this, if not closed, would become a compensating tide-way allowing contraction of any other body cavity. Such a function at once makes the anus more or less of a respiratory center and in some Echinoderms it has become highly specialized as such.

Passing from the case of one special subtegmental respiratory sac to one of two or more we will readily see that the ejection of the contents of one would mean simply the filling of another if only it were passive at the time, and that a long series of such structures could be emptied and filled by a rhythmical and progressive or peristaltic contraction. It must be borne in mind, however, that no matter how complex such a system may become the contraction of any portion of it will be felt immediately by all other organs and the tendency to make these others auxiliary organs of respiration will be always present. This tendency is of course controlled by natural selection and the adaptations secured are varied and often present a very high degree of specialization.

The other path, or that of exothecal respiration, presents no exception to the principles already stated. The contraction of any one of these exothecal sacs would be impossible unless its contained coelomic or other fluid was allowed to flow back under the theca and such a flow would be impossible unless fluids already in that position were allowed to distend other exothecal sacs or were discharged directly into the sea and thus lost to the organism.

Specialization of exothecal respiratory processes. Such exothecal sacs as we have just discussed, whether papulae or podia, involve a new series of adjustments to environment, for their position renders them liable to attack from other creatures. Protection may be secured in three directions. First, by the power of rapid withdrawal into or under the plate, as in *Cleiocrinus* [see fig. 2

p. 213], or into tubelike extensions of stereom similar to those presented by *Caryocrinus ornatus*. This power of rapid withdrawal requires a higher muscular and nervous development. If the sac is not attached to the stereom surrounding the pores it may be withdrawn as a whole but if so attached it must possess internal muscles reaching to its distal end and be withdrawn by invagination. Here we have opened still other lines of specialization in which we shall find these processes functioning as sense organs, as organs for food capture, and as organs for locomotion. Second, while retaining their high nervous and muscular development, these structures might be protected by clusters or fringes of immovable or movable spines such as we see so highly specialized in Asteroids and Echinoids. Third, these structures might early seek protection by means of porous coverings of epistereom. Under this condition the external sacs or tubes would of necessity come to lie close to the thecal surface or in special depressions on the latter. Such respiratory processes should be distinguished by the term epithecal. Development in this direction led to considerable complexity of structure but it never favored complexity or specialization of function. This third direction was chosen by many cystids and crinoids and we shall find interesting examples in *Palaeocrinus* and *Palaeocystites*. The tendency toward the development of a solid thecal wall by a creature living in an incompressible medium has thus led to the concomitant development of a system or systems of hydraulic structures whose evolution may profitably be studied from a purely mechanical point of view.

Respiration in Blastoidocrinus. At the time of publication of my description of *Blastoidocrinus*, in Bulletin 107 of the New York State Museum (1907), I had not seen Billings's type. Through the kindness of the late Dr J. F. Whiteaves I have since been enabled to give it long and careful study and it has yielded evidence of very great interest concerning this question of respiration. From numerous photomicrographs made of features presented by this type, nine have been chosen to illustrate the present article and will be found reproduced in plates 1 to 4 inclusive. It will be seen that we are dealing with the second form of endothecal respiration which we have tabulated and already briefly discussed.

In figure 2 of plate 1 of this paper we have a side view, $\times 10$, of a pseudambulacrum from which the wing plates and nearly all traces of the brachioles have been removed by natural processes.

The oral end is toward the left and it will be seen that the covering pieces *a* increase rapidly in height with age while at the same time they increase very little in thickness. The row back of these is seen in part, though much out of focus. The upper surface of the two rows presented a shallow channel into which the long and solid wing plate, whose under surface is shown in figure 1 of the same plate, fitted tightly, as is shown by the impressions made by these covering pieces on the under side of this wing plate. Thin sections of the wing plates show them to be homogeneous in their nature and not formed by the fusion of smaller pieces. These plates serve to lock the covering pieces and with them make a very high and solid covering over the food groove.

Directly under the covering pieces are seen the outer edges of part of a row of adambulacrals, one member of which has been marked *b*. The sutures between the covering pieces and the adambulacrals can not be clearly seen on account of a thin veil-like band of calcite which seems to indicate that the brachioles were attached to the side of these plates, helping also to make a solid structure of a pseudambulacrum. The veil-like band but slightly obscures the openings into the food groove. The remnants of brachioles which still adhere to the specimen at the left show that the food and water channels crossed the outer faces of the wing plate and covering pieces at an angle of about 25 degrees with the edge of the deltoid and on arriving at the openings into the food grooves turned abruptly and ran down to the edge of the deltoid (pl. 1, fig. 2, *d*) at an angle of 90 degrees or parallel with the deep vertical channels which run down between the adambulacrals. These channels lead to the openings into the hydrospires. The lower portion of the outer edge of an adambulacrum presents a flat face against which rested one or more of the basal plates of a brachiole. Above this the outer face of an adambulacral becomes narrower and more rounded. This is the region where so much light was admitted through the rather thick section drawn for figure 2 of Bulletin 107, page 105, and which suggested "brood chambers." Taking the evidence of the cross section and that now before us we may safely conclude that water passing down the brachioles could enter any one of a series of openings into the food groove and that surplus water, or water deprived of its food content, could pass down any one or more of the vertical side channels and find an entrance into the hydrospires. On page 114 of Bulletin 107

reasons were given for supposing that the flow of water through the central and older hydrospires was much more copious than the flow through the more lateral and younger hydrospires. That they could so function is now very manifest for there were undoubtedly two water streams, one along each side of the heavier pseudambulacral plates (ten such streams in all) which would serve to augment the flow through the larger hydrospires. Two of these streams near their meeting point received the ejecta of the completely covered anus and swept it through the largest hydrospires of a single deltoid. Even here the volume of oxygen-bearing water must have been in excess of the deoxygenated stream from the alimentary canal and the hydrospires involved would still in a measure carry on their primitive function of respiration.

Figure 3 of plate 1 shows the upper surface of an arm of the type x10. All the covering plates, save six near the end of the arm, have weathered away. Five of these are over the upper (in the figure) row of adambulacrals and the smallest end one over an adambulacral of the lower row. These plates have lost somewhat through weathering but as end and newly-formed plates we should expect them to be small. A portion of one row of adambulacrals is also lost but the outer edges of the remaining plates show clearly the openings through which the surplus water drained into the hydrospires. These openings are between the plates but perhaps a little nearer their outer ends than such pores appear to be in the *Blastoidea*. In fact it seems that in *Blastoidocrinus* the outer edges of the adambulacra did not meet beyond the opening. The vertical channels with their lateral connections shown in figure 2 were probably covered by a membrane possessing ciliary processes, and these accomplished the separation of the food particles and directed them to the food groove. Hambach's beautiful drawing of a portion of the pseudambulacrum of a specimen of *Pentremites sulcatus*, [see fig. 5, plate 2 of his "Revision"¹] shows what was very probably a similar arrangement with the marked difference that the collecting floor is at right angles to the direction of flow through the pores in *Pentremites* and parallel with it in *Blastoidocrinus*. Each pore in *Pentremites* is figured as passing into

¹ A Revision of the *Blastoidea* with a Proposed New Classification and Description of New Species, by G. Hambach, St Louis, Mo. 1903. Nixon-Jones Printing Co.

a common hydrosphere and therefore no necessity exists for communication of water channels before discharging into the hydrospheres as in *Blastoidocrinus*. Hambach's drawing seems to show that the water flow from each brachiole was kept distinct until it entered the hydrosphere. Figures 4 and 5 of our plate 1 show portions of the other two arms possessed by the type. The remaining two arms had evidently been weathered away before the specimen was found. They show similar characters to those found in figure 3 but figure 5 is of additional interest, as it seems to show a tendency to pass from an alternate arrangement of ambulacra to an opposite arrangement. The point of the adambulacral marked *e* is very close to the middle of the end of the plate. As we pass to the left the plates become very markedly more opposite in their arrangement. The oral end of figures 3 and 5 is at the right.

Figure 1 of plate 2 presents a side view of the terminal area of the pseudambulacrum already represented in plate 1, figure 3, and with the same amplification. The food groove is clearly seen at *a*, partly roofed over by the covering plates already noted. At *c*, *d* and *e* the inner, vertical, closed edges of three hydrospheres belonging to the rear row of adambulacra, may be readily recognized. The two hydrospheres to the right of *e* have had their inner edges weathered away and show the beginning of the sheetlike cavity down and through which passed the surplus water of the brachiolar streams. At *f* the surface of the deltoid has been carried away and the character of the understructure of mineralized sheets brought to view. A portion of the undersurface of a deltoid $\times 10$ is shown in figure 2 of this plate. At the left of the center of this figure is an area that shows better the nature of the respiratory sheets, for their thin edges may be clearly seen. The line marked *b* in figure 1 separates the deltoid from a bibrachial. Near the right end of this line are several openings along the base of the deltoid. These are the exits of the hydrospheres. They become larger passing in toward the older, longer and deeper hydrospheres. This is another indication of that greatly increased outflow caused by the lateral water streams already postulated. In some of the adambulacra shown in plate 1, figure 2 and in plate 2, figure 1, the lower outer edges are not in contact with the deltoid. This is probably due to the fact that the organic membrane which occupied this position and was subsequently mineralized, has now been partly removed through differential solution.

The two figures of plate 3 present views of different portions of the area partly shown in plate 2, figure 1. The broken inner edges of the two rear hydrospires to the right of *e* are better shown, and next to these is a hydrospire that still retains a portion of its inner rounded edge. The suture between deltoid and bibrachial is reproduced without retouching and the hydrospire exits show their beautifully arched upper surfaces. The lower figure presents a region farther to the right, shows several interbranchials with the still higher and larger hydrospire exit above them and at *f* shows a single hydrospire sheet that was washed with water on its left face and bathed with coelomic fluid on its right. The right side of this wall presents fine vertical lines which are easily seen in the photograph and which it is hoped will be still present in the reproduction. This appearance of corrugation in the walls of the hydrospires was first noticed in a fragment now in my possession and was mentioned in Bulletin 107, page 107. This corrugation securing strength with extreme thinness (the sheets in the figures of this plate represent secondary thickening that took place long after death) is also strongly indicative of the function of respiration.

If to the evidence here given we add that presented by the cross section of a deltoid and two pseudambulacra, figured in Bulletin 107, page 105, we must agree that we have as complete a case as can be desired. In that section we found limonite-colored muds in each and every one of the cavities through which we maintained that there was a flow of water and these muds were not detected in any other position save that of the intestine.

These observations may serve to throw some light on the Hambach-Carpenter controversy which I had not seen at the time of making my first description of Blastoidocrinus (Bulletin 107, 1907). I am greatly indebted to Mr Edwin Kirk for recently loaning me these papers. There seems to be no doubt but that we may accept the essential correctness of Hambach's cross section of a Blastoid pseudambulacrum as shown in plate 2, figure 8 of his "Revision," with the exception that the pores communicating with the hydrospires should open through the membrane covering the floor of the extended food groove area. Doctor Carpenter has stated that Mr Hambach "must have a wonderful power of imagination; for he actually believes that 'soft and membranaceous organs, such as occupy the pores of the ambulacral field in Echinoderms' can have been preserved

(in a collapsed state, it is true) through all the ages of the Carbonic period and the present time.”¹ We must regard criticism of this character as at least unfortunate. In New York State Museum Bulletin 107, page 106, I have given reasons for believing that the inner edges of the hydrospires were membranous at death, yet their carbonized outlines have remained, and for the greater part in their original position, from Chazy time to the present. Traces of just such membranes will be noted in the description of *Palaeocrinus striatus* Bill. on p. 218 of the present paper. The more difficult the field in which one is working, the greater is his liability to error. If one is made to feel that it is a disgrace to err at all in such a field and that any admittedly speculative matter will receive censure, it can only follow as a consequence that very much valuable observation and suggestion will die with the mind of the worker and perhaps not appear again for centuries. Encouragement to work in such difficult fields is what is needed. Cross-fertilization of mind followed by just and searching criticism will bear only good fruit. Ham-bach is very probably correct in attributing the structures represented in plate 2, figure 1 of his “Revision” to collapsed membranes in the poral openings. That they were “tentacles,” however, is exceedingly doubtful. We may, I believe, accept Doctor Carpenter’s contention that the mouth, food grooves and pores were covered with small but well fitting plates. With this covering we have all the essentials of a food-capturing and respiratory system very similar in nature to that here presented for *Blastoidocrinus*.

ADDITIONAL REMARKS ON BLASTOIDOCRINUS

From various other points of interest connected with this Canadian type we may select that concerning the penetration of the stem so far into the interior of the theca. Billings believed² that the position shown in our plate 4, figure 1, was a natural one. A careful examination of the type convinced me that an additional portion of the stem was still to be found below

¹ Ann. and Mag. Nat. Hist. ser. 5, 8:423.

² In Canadian Org. Rem. Dec. IV, p. 21, Billings says “the column actually penetrates into the interior, nearly if not quite to the top of the visceral cavity. This is so extraordinary a structure that scarcely any paleontologist at all well acquainted with the organization of the Crinoidea could be brought to believe it without personal inspection of the proofs.”

and at the right of the main portion preserved. On receiving permission from Doctor Whiteaves to uncover a portion of the specimen in this region three additional rings were found within the cup formed by the strongly bent-in edges of the radials. It will be seen from the figure that these occupy the right-hand side of the cavity and that the end of the longer portion of the stem was thrust to the left-hand side. Figure 2 of this plate shows the upper portion of the stem photographed through a gum dammar mounting with a 3-inch objective and given an amplification of 10. The outlines of the basal and of the stem lumen are clearly seen in the upper part of the figure. It will also be noticed that the plates of the stem have been displaced, those just above the center of the figure having been shifted to the left. There are no plate edges connecting these basals with the radials. It seems evident that the stem was thrust up into the body cavity and that the basals parted from the radials. When the cap of basals met the inner edges of the hydrospires, the advance of the stem was stopped. Continued pressure bent it into something of a letter S form (a portion of which lies in the vertical plane passing from front to rear), displaced its joints above, severed the stem about the middle of the basal invagination of the theca or just where the lack of lateral support might cause the break, and pressed the broken end of the balance of the stem as far into the same cavity as its walls would allow. The original depth of this basal invagination was about half that assigned to it by Billings. The radials themselves show evidence of crushing and the type has suffered some distortion. Some of the details noted would seem to indicate that the form was monocyclic.

Plate 4, figure 3, presents a small area of the right-hand side of figure 1, $\times 10$. We may here again see the closed inner edges of the hydrospires which have so weathered above as to reveal their two-walled character. It is to be regretted that the type shows none of the plates of the peristome. The question as to whether the deltoids are true orals or not must for the present be left open. The visible apexes of the deltoids of the Valcour island specimen are arranged in a circle having a diameter of about 10 mm. The fringe of brachioles and the apical piece completely cover this area, yet within this circle a number of plates might be concealed and here also is the mouth, the anus, and the genital pore or pores.

One interambulacral area seems to have been freed from the matrix by the use of a knife or file. In the process a portion of the

interbranchials was lost but structures below were revealed. There is evidence here that the hydrospires descended internally to a position below the base of the deltoid, thus further increasing the respiratory area.

In figure 1 of the text we have presented a part of the lower edge of a deltoid x10. The inner surface is shown and from its

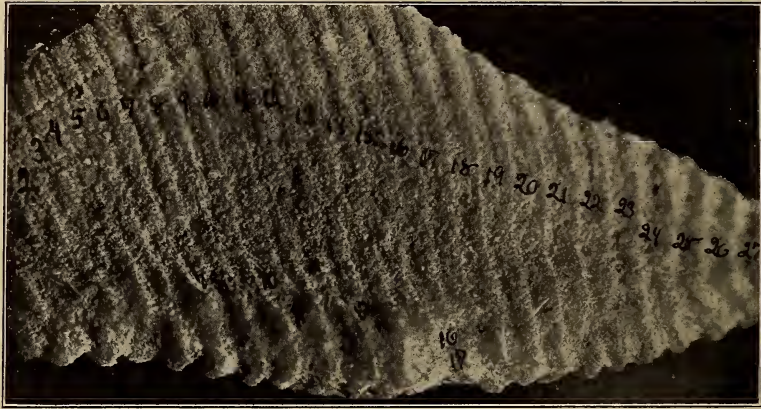


FIG. 1 From a photomicrograph of the under surface of the deltoid figured in Museum Bulletin 107, plate 5 at 0. x10. Add ten each to the number here used and they will correspond with those used in the former reproduction.

study we may conclude that with the downward extension of the plate it often happened that two hydrospire exits were merged into one. The grooves here marked 7 and 8 find only one exit. The same is also true of pairs 10 and 11, 13 and 14, 16 and 17. Hydrospires numbered 21 and 22 appear to have had the choice of either their own opening or that of their neighbor. Anastomosis of these sheets would hardly be of enough advantage to become the subject of natural selection as the stoppage of any one exit would not interfere either with the food-getting capacity or with the waterflow down its own brachiole. Such stoppage would only mean a slightly faster flow through the numerous other hydrospires, attached to the under surface of half a deltoid. With a more primitive form in which there was no anastomosis of streams above the hydrospire pores such anastomoses below them might prove of great value and ultimately lead to structures like the hydrospires of the *Blastoidea*.

In *Canadian Organic Remains*, Dec. IV, p. 21, Billings said of the stem that it was "round, with an alimentary canal so small that often detached joints seem to have no central perforation . . . the flat faces of the separate joints exhibit strong radiating

striae." On plate 7 of Bulletin 107 I figured some stem joints and roots, answering this description, which were associated with Blastoidocrinus remains. I there said that these "may belong to this species." A careful examination of the type shows that the joints of its column are not like those figures. The stem joints of the type have convex rather than cylindrical edges and I do not find any evidence for the possession of "strong radiating striae" on their flat faces.

No sutures could be seen on the stem joints even when examined under water in sunlight with a compound microscope. The lumen seems to be very small but may weather out to leave "rings" like those which are also abundantly associated with the remains of Blastoidocrinus on Valcour island and elsewhere.

Genus **CLIOCRINUS** E. Billings. 1856

Among the crinoid remains of the middle Chazy of Valcour island are some well-preserved plates of Cliocrinus clearly showing, along the lines of suture, a series of cylindrical perforations which are perpendicular to the surface of the plates. The largest fragment found contains but little more than thirty plates, yet these present characters which (aside from the horizon from which the specimen was taken) indicate that the form is specifically distinct from the described Trenton species. As I wish to make several references to this Chazy form and as I believe its plates show characters which may be recognized in more complete specimens, I have made it the type of a new species.

Cliocrinus perforatus nov.

Description of the type. Brachials differing from those of *C. magnificus* Bill. in the possession of a low median vertical fold about 0.2 mm wide. The fold shows more clearly at the middle of the plate where there is a shallow depression on each side of it. Both above and below these depressions well-marked plates, like *a* and *f*, figure 2, have a transverse thickening which raises the plate surface nearly to the level of the median fold and gives the latter two widened moundlike areas on each plate. The species differs from *C. regius* Bill. in the absence of the much narrower, higher and sharply defined median folds of that species. The larger cylindrical pores, 0.15 mm in diameter, are situated one on each side of a median fold where the latter crosses a suture. These pores are 0.4 mm from center to center. On either side of these are one or more smaller pores with their centers about 0.2 mm apart.

There is usually a pore exactly at the corner of a plate with three or four plates uniting to form its walls. The vertical sutures also possess one or more pores besides those common to both vertical and horizontal sutures. The corner pore and the three which immediately surround it together occupy a shallow basin formed by the thinner and depressed corners of the joining plates. Such a basin is well shown at the left end of the suture between plates *a* and *b*, figure 2.

Nature of the pores in C. perforatus. In an aquarium specimen of *Asterias forbesii* under my observation, the papulae average about 0.2 mm in diameter and, while the pores of *C. perforatus* are slightly smaller, they strongly suggest canals for the extrusion of similar respiratory processes. These pores, and others of like nature, will be hereafter called *sutural canals*. The position of the larger and first formed sutural canals of *C. perforatus*, between brachia and on either side of the axial fold, is very suggestive of connection with the water vascular system. If such was the case the protruding respiratory processes might be considered as homologous with podia though not functioning as organs of locomotion. How many of the arm plates lie below the horizon of the tegmen in this genus is not known, but the permanently closed condition of the arm bases must have tended to make functionless (in a respiratory sense) the podia perhaps formerly possessed by this region. This would rather strengthen the idea that these external processes were developed to compensate for the loss of the others. Very similar structures in *Palaeocystites*, to be discussed farther on, are more suggestive of papulae or external extensions of the coelomic cavity, and as the arms of crinoids carry extensions of this cavity one could with equal propriety maintain that the structures in question were simply papulae such as we find on the aboral surface of asteroids. It becomes desirable then to have a term which we may use to designate all forms of exothecal or epithecal respiratory processes regardless of the character of the subthecal cavities into which they may open and though the term branchial vesicles has been used as synonymous with papulae, we shall take the liberty of using it here in the broader sense given above. As the use of the term will be frequent we shall abbreviate it to b.v. or b.vs. It seems fairly reasonable to hold, at least temporarily, that the sutural canals of *C. perforatus* were occupied by b.vs. and that these were sensitive and protected by possessing the power of rapid withdrawal. *Cliocrinus* would thus become an example of the first direction of b.v. protection outlined on page 202.

Development of brachials and sutural canals. The plates of *C. perforatus* have something to tell of their own growth and development. The greatest width of plate *a*, text figure 2, is 1.9

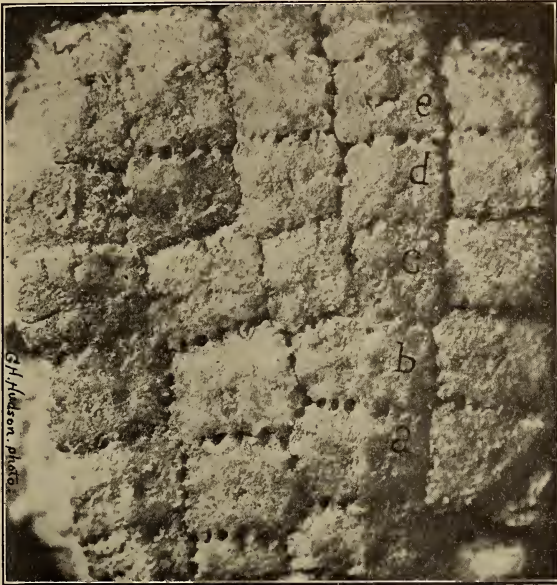


FIG. 2 From a photomicrograph of a fragment of *Cliocrinus perforatus* $\times 10$. This fragment is designated as the holotype of the species and is in the State Museum collection.

mm and its primitive pair of b.v.s., both above and below, measured 0.43 mm from center to center at death. Plate *e* has a width of but 1.4 mm, yet its primitive pair of b.v.s. have the same 0.43 mm between their centers. In the earlier stages of plate *a* the distance between its primitive pairs of b.v.s. was no doubt but little if any less than at death. If we should outline the plate when it was about one fourth the diameter attained at death we should find it possessed a median fold nearly as wide as the plate itself and with but two b.v.s. on each horizontal suture. The addition of stereom to these sutures has carried the two pairs of b.v.s. directly away from each other and increased fourfold the vertical distance separating them, yet one member of a pair has not perceptibly increased its horizontal distance from its neighbor.

If any horizontal suture should happen to lie in line or nearly in line with another at the right or left, one primitive b.v. of a pair would find itself in close proximity to one of the members of a neighboring pair. These two unfortunately situated b.v.s. would

naturally bend away from each other in performing their function and the widening of the plates would soon not only separate them, but would place each in a position on the suture instead of at the corner. The corner would thus soon offer a free position for the protrusion of a branch b.v. which would increase the respiratory area. Should any b.v. thus protruded remain at the corner it would tend to stop the development of any new branches. It is very likely, however, that more than one would seek the same corner and their development would again insure their bending away from each other. In this case greater freedom for function would be found on a vertical suture and the growing corners of the plates would soon push by the b.vs. and leave them in a fixed position on the vertical sutures. Still newer b.vs. would be led to take positions giving most room, which this time would probably be again on the horizontal sutures. If the plates produced more stereom on the vertical than on the horizontal sutural faces, the horizontal sutures would become the longer, offer the most freedom for function, and come to contain the greatest number of b.vs. A b.v. next to a member of a first pair would keep it from increasing its distance from its neighbor and a new b.v. at the corner would have the same effect on the last previously formed. It would thus happen that the distance apart of these structures would become fixed and not increase with growth though the number would increase. The distance apart of the primitive pairs of b.vs. might easily become a specific character.

The newer b.vs. in our species are all smaller than the members of the primitive pairs and they are set nearer each other. The average distance of the three around the corner b.v. at the left end of the suture between *a* and *b*, figure 2, is 0.19 mm. The size and distance between the newer b.vs. are also likely to be specific characters.

A closer examination of the group of b.vs. just mentioned will reveal several additional points of interest. The central one evidently emerged before the others had become completely inclosed by the growing plate corners (see text figure 3, which presents a still greater enlargement of this area). These all seem to be branches of the left-hand member of the pair between *a* and *b*. It sent off five branches. The widening of the plate allowed two branches to remain on the same suture, two on the vertical and one at the corner with no newcomer to dispute for its territory. The b.vs. have been numbered in the order of their distance from the angle of the plate.

This would probably also indicate the order of their appearance if *plate increase was equal on all sutures*. Plate *a* seems to have

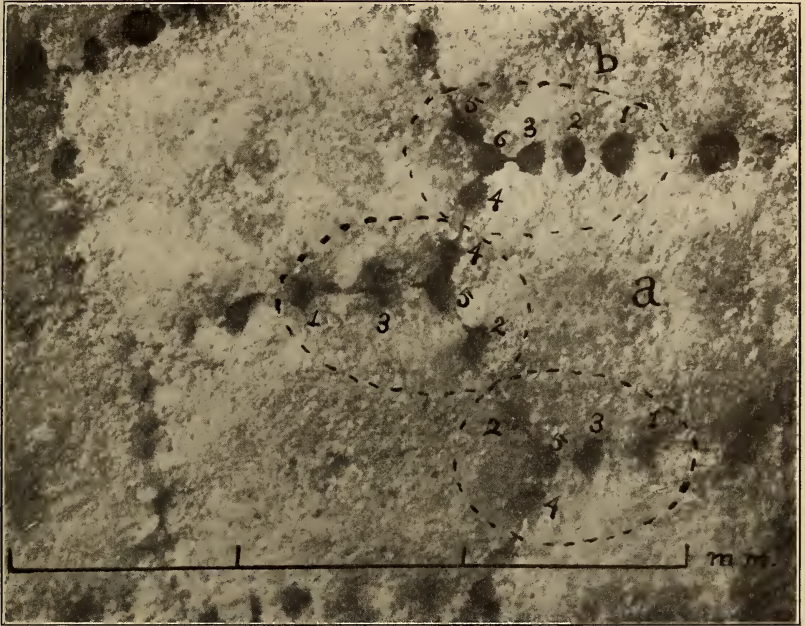


FIG. 3 Represents a small area of figure 2 still further enlarged. The dotted lines are used to separate related groups of brachial vesicles.

added more to its lateral than to its horizontal sutures and the numbers used may thus fail to designate age. B.v. 6 was the last formed and nos. 4 and 5 of the same group are so near to it that they have hardly yet been separated from it. Continued addition to the plate edges of this region would more and more separate 4 and 5 from 6, providing that the latter remained at the corner. The distance between 3 and 6 being the greater, it is likely that an additional 7th b.v. might make its exit on this side of 6 or that 6 itself would become forced to take up a position on the suture next to 3. The b.v. at the extreme left angle of *a*, with the three nearest to it form a group belonging to the right-hand member of the primitive pair occupying the horizontal suture to the left of this point. Conclusive evidence of such branching, forming groups, is not presented by this specimen, but it will be seen in *Palaeocrinus* and in *Palaeocystites*. The dotted lines of figure 3 surround groups of b.v.s. which are supposed to be related as suggested above.

A tendency of these sutural canals to become oval in cross section and with the major axis at right angles to the sutures is clearly seen at several places in figure 3. It probably represents the effects of the bending of the free ends of the b.v. to assume the most favorable positions for the performance of their function, which would be toward the freer area of the enlarging plate surface. It will be seen that this influence has led not only to just such widening of the sutural canals in *Palaeocrinus* and *Palaeocystites*, but it has been followed by an actual bifurcation of the b.vs. themselves.

Plate *a*, text figure 3, also shows a periodic variation in thickness. It was thin in its nepionic stage and thickened, particularly along its horizontal sutures, during its adolescent stage. There was thus left the two nearly central basins or shallow depressions, one on each side of the axial fold, which represent the early lateral margins of the plate. Either the impetus gained through the development of plate thickness carried the form beyond the requirements of its environment or the later environment became less exacting in this respect, for during the ephobic stage the plate appears to have built its edges with stereom of diminished thickness. To this third plate stage is due the shallow basins at the corners which resemble the nepionic basins nearer the plate centers.

Palaeocrinus striatus Billings

Canadian Org. Rem. Dec. IV, 1859, p. 25, pl. 1, fig. 5a-5b

Cup analysis. Through the courtesy of the late Dr J. F. Whiteaves of the Geological Survey of Canada the writer has been enabled to give long and careful study to Billings's type of this genus and species.

The cup analysis here given, figure 4, differs very materially in the form of its RA and adjacent plates, from the cup analysis given by Bather in "A Treatise on Zoology," part 3, p. 172, and also from the very conventional analysis given by Billings, loc. cit. p. 24. Failures to present a correct cup analysis of the genotype have been due to very great difficulties presented by the specimen itself. It was evidently found lying in the bedding plane with its anterior side uppermost, as this surface is most weathered (fig. 6). Below this is a belt more recently separated from the matrix and presenting some plate details in great perfection (fig. 5). A knife seems to have been used to free the attached posterior area by cutting under the anal plate from the oral end. Portions of *x* and RA were cut nearly or quite through and the surface lost. On final liberation post. B, 1.

post. B, and l. post. IB were badly shattered and the greater portion of the surface of these plates was left on the bed. For an enlarged

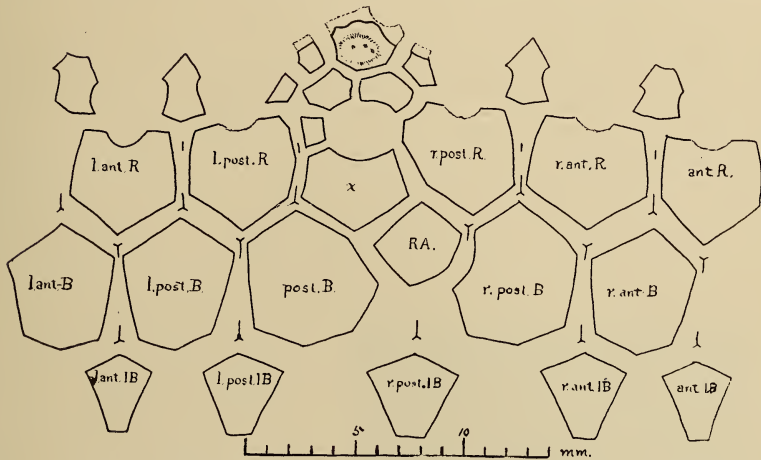


FIG. 4 Analysis of *Palaeocrinus striatus* Billings. The following abbreviations are used here and in the text: l=left, r=right, ant.=anterior, post.=posterior, IB=infrabasal B=basal, R=radial, RA=radial and x=anal. The dotted boundaries show probable edges of plates where covered. The marks lying between plate corners are supposed centers of development of branchial vesicles.

view of part of this area see plate 6, figure 1. Mr Billings realized the difficulty of determining the character of the damaged area for under the cut representing his cup analysis, he said "The azygos

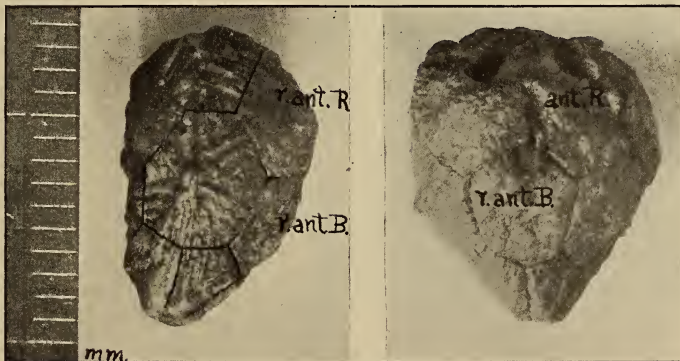


FIG. 5, 6 Different aspects of the holotype of *Palaeocrinus striatus* Billings, x31

interradial space is left blank in the figure as it is not certain how many plates it contains."

Method used to determine sutures. For a long time the writer tried to see the sutures of the injured area with a three inch objective

and draw them with a camera lucida but, while enough could be seen to show that former analyses were certainly in error, yet lines seemed to be absent where sutures were expected and faint or fragmentary lines suggested sutures where they were not expected. Remembering a former successful showing of a vertical section of the basals of *Blastoidocrinus* by photographing a portion of Billings's type under a mounting of gum dammar (see plate 4, fig. 2) a similar trial was made with the damaged plates of *P. striatus*. A drop of pure benzol was placed on the area in question to exclude air bubbles and a drop of gum dammar, dissolved in benzol, added. A little of the dissolved gum was also placed on an ordinary round cover glass for microscope slides and the cover placed over the area. This was allowed to dry enough to retain its position and more of the mounting fluid then added in order to show as large an area as possible. After a second partial drying the region was photographed with a three inch objective, using a black hood over the lens to avoid reflections and with bellows extended to give an enlargement of ten diameters.

Advantages of the method. The photographs for figures 2 and 4 of plate 5 were made in this manner and a comparison of them with figures 1 and 3 of the same plate (from photographs made without the mounting) will reveal several peculiar advantages of this method. Reflection from the summits of plate granules, tool marks, scratches and small crystalline faces of broken calcite have been reduced to a minimum and much of their distracting influence on the eye removed. Refraction has relieved the surface shadows cast by minor elevations and has also admitted light to the deeper features of plate detail, making structures visible that were heretofore obscured or lost. On the more uniformly lighted surface so produced the difference in the amount of free carbon now held by the calcite is quite clearly revealed and the former presence of organic membranes made manifest. It will be seen that the sutures stand out clearly as black lines of uniform width and all of the sutures of the damaged area were not only thus made clearly visible under the microscope but were secured on negatives. The photographs for other figures were also prepared in this manner and the features so revealed will be described in their proper places.

Nature of the plate ridges. The figures on plate 5 represent two different areas of the specimen and show the ridges as they appear on IBB, BB and RR. They are seen to be arranged in groups the members of which are rather evenly spaced, of regularly varying

lengths, parallel to each other, nearly perpendicular to the sutural lines and bisected by the latter.

These ridges are covered cylindrical, epithecal extensions of sutural canals and each was occupied by a bifurcating contractile b.v. whose arms lay parallel to the plate surface and communicated with the interior only through the sutural canal itself.

In support of the above assertion we may first examine figure 1 of plate 5, which presents a detail of the left posterior margin — a portion of the best preserved belt of the specimen. Erosion, though slight, has carried away just enough of the crests of some of the horizontal ridges to reveal in part their hollow nature and at *a* an ascending ridge has been so broken across that a portion of its cavity is clearly brought to view.

Text figure 7 represents a portion of the right posterior margin, a detail from the opposite edge of the best preserved belt. The ascending ridges have had their crests removed to a still greater extent and the broken edges at times reach deep enough to reveal nearly the full width of the canal itself.

That these structures were epithecal, that is laid down over the mesostereom, and that they have no communication with the interior through the plate itself, is shown by text figure 8, which represents that portion of the specimen which we have already considered as lying uppermost in the bedding plane and which was therefore the longest exposed

to the effects of weathering. The r.ant.B. has lost nearly all traces of its canals, but the floors of these structures may be seen on the margins of the adjacent plates to the left and we have to pass but little distance over the edge of r.ant.IB to reach the less weathered belt and find at *a* and *b* first the side walls and then the canal coverings.



FIG. 7. View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, $\times 10$

The value of study under the dammar mounting may now be seen by an examination of plate 5, figures 2 and 4. In the former the area of figure 1 is again presented, but the fragmentary matter covering the epithelial canals has been rendered more transparent by the mounting medium and the band of carbon deposited by the decaying b.vs. brought more clearly to view. The boundary between

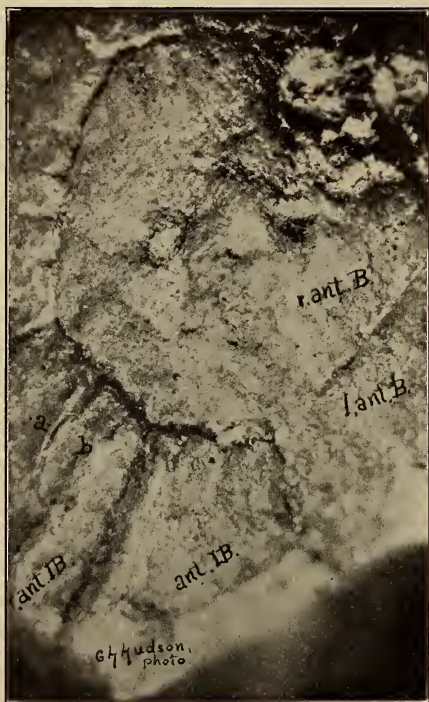


FIG. 8. View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, x10

this darkened belt and the clearer calcite of its side walls is well marked and makes the measurement of the canal diameters an easy matter. Their full width is found here to be from .10 to .12 mm. This agrees closely with that of the ascending ridges of text figure 7 and the uncovered regions on text figure 8.

Plate 5, figure 4, presents portions of the two radials over r.post.B. The longer canal of the horizontal series shows not only its cylindrical character but its floor as well. Near the suture this floor dips into a depression whose deeper portion is filled with limonite-colored mud. This

darker area seems also to be wider and to run under the remote edge of the canal where the latter reaches the suture. We have here an oval basin whose major axis crosses the sutures and whose minor axis is nearly twice as wide as the bore of the exothecal canal which enters it on the left.

The basin just described is but the outward expansion of a sutural canal and below it two others as well shown. The sutural canal next above the one with the longest exothecal canal was weathered out more completely and for some time after mounting its communication with the interior was made manifest by the bubbles of air which rose from it and moved away through the thin mounting medium.

While this medium was becoming more viscid, bubbles continued to rise, though at longer intervals. The figure shows a compound bubble and a small new one just next to it, the aggregation not having moved out of the field of view before the exposure was made. Figure 2 of this plate also shows evidence for these canals, particularly at the aborad ends of the two BB.

In plate 6, figure 1, we have evidence of a different character to offer. This figure represents the area cut under to liberate the specimen from its bed and the cutting was in a sense fortunate for, although it removed all surface features and even the epithelial canals themselves, it gave us some cross sections of the sutural canals and to some of these we will give brief attention.

Five millimeters to the left of the orad apex of post.B is a shaded area crossing the suture at right angles. This seems to indicate the former presence of an epithelial canal now cut away. Occupying this shaded area is a circle 2.3 mm in diameter which is clearly outlined by the carbon black remains of its former organic walls. Seven millimeters to the right of the orad angle of this basal is another sutural ring of similar character, measuring 1.7 mm in diameter and 5 mm to the right of this is an oval similarly outlined. This oval has a minor axis which measures 2 mm and a major axis of 3.3 mm, the latter at right angles to the suture. Both the specimen and the negatives show a much smaller ring on this suture at a point 2 mm to the right of the upper angle of the basal, but its position in a shadow effectually prevents its being recognized in the figure.

The carbon blackened rings, their position on the suture, their distance from the apex of the plate, their distance from each other, the position at a transverse shading, their diameters, and the transverse position of the major axis of the oval; all indicate these structures to be cross sections of cylindrical canals. The oval is evidently a cross section made nearer the surface of the plate or where the floor of the two wings of an exothecal canal dipped down to make a junction with the sutural canal. In other words, this is a cross section of a sutural basin like that already noted in plate 5, figure 4. The diameters of the rings last measured (.023, .17 and .2 mm) give an average a little larger than that obtained from the measurements of the sutural canals of *Cliocrinus perforatus*, but they are remarkably close to the measurements of the papulae of the aquarium specimen of *Asterias forbesi*.

Before leaving the discussion of function we must note that it raises a question as to the nature of the canal coverings. With contractile b.v.s., such as are here postulated, there must be some provision for filling with fluid the space between the canal wall and the b.v. during the contraction of the latter. With a canal covering formed by an impervious sheet of epistereom, the compensating fluid would have to be drawn from beneath the theca and, as there is no evidence for any pores through the mesostereom itself, such fluid would have to ascend in the vertical canals and outside of the tubular walls of the b.v.s. The larger diameter of the sutural canals would allow them to serve such a purpose. We have evidence, however, that the canal coverings were not impervious and that water could enter the canal from the outside on contraction of the b.v. within it. An examination of the ascending canals on the basal represented in plate 5, figures 1 and 2, shows a line of very porous epistereom lying directly over the canal. Where the covering has been broken away, as at *a*, this seam of porous epistereom is seen to penetrate to the canal itself. The thickness of this epistereom, and yet the maintenance of the porous seam, is very decided evidence for the respiratory nature of the structure. Text figures 4 and 5 show this same feature and also suggest that with the external thickening of the ridge the deeper layers of the porous epistereom were absorbed, thus leaving a narrow slitlike cavity over the b.v.s. The thickening of the ridges was by growth on the outside and a new sievelike epistereom was formed over the more porous older material. Water evidently filtered through these lines as through a madreporite. The study so far given seems abundantly to justify the conclusion that we are dealing with respiratory processes and this conclusion is but strengthened when we note that they form an elaborate system and cover all the plates of the theca.

Whether or not one accepts the interpretation here given, we may note that the evidence so far presented is very decidedly against certain former interpretations. These ridges are most certainly not "axial folds of the plates" as others have called them. They are not in any way indicative of nerve branching to supply distant organs, nor do they indicate either "incipient hydrospires" or the former possession of such structures. The suggestion that we here have grooves for stroma strands or for muscular processes is negated by the deepening of the surface

canals at the suture to form pelvislike depressions that communicate by a vertical canal with the interior. If *Palaeocrinus*, with practically only three circlets of plates of five each, needed such an elaborate system of stroma strands or muscular processes to hold its plates together, why do we not find a similar arrangement in *Cliocrinus* with its hundreds of separate plates? These structures are canals and each was occupied by a branchial vesicle.

Plate development and the serial formation of branchial vesicles. An examination of plate 5 will show that the epithelial extensions of the b.v.s. become shorter and less prominent as we pass from the middle of sutures toward their ends and figure 1 of plate 6 will show that the shortening is correlated with a decrease in diameter of the sutural canals. On this evidence we should be warranted in assuming that these structures were serially formed and that those nearest the ends of the sutures were youngest.

As the lateral extension of a plate takes place only by the addition of stroma to its margins we may, without great error, outline a plate as it existed in some earlier stages of its development. This we have essayed to do in text figure 9. It will be at once seen that the smaller the size we make the plate the fewer b.v.s. it could have possessed and the inner outline shows a condition where there was but a single b.v. to a suture. These are at the ends of those longest epithelial canals which we have already determined to be the oldest and the shorter ones simply did not exist at this time.

We may express a law concerning these b.v.s. as follows. On any suture the longest b.v. is the oldest and the newer members were added serially on one or both sides of this as the suture was



FIG. 9. View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, x10. Outlines show probable forms of the plates at earlier stages in their development.

extended. If now these plates have so grown as to give their common sutures equal extensions, it will follow that the distance of any b.v. from the point of meeting of these three sutures is proportional to its age, provided we do not pass the middle of the suture or the longest exothecal canal which crosses it. Let us apply this rule to the region around the orad angle of r.post.B.

The primary interradial groups of branchial vesicles. On the photographs used for figures 3 and 4 of plate 5 was measured the distance of the middle of each sutural canal from the apex of the orad angle of r.post.B. The average of each pair of measurements was taken as the distance of the b.v. in question. These positions are now indicated by dots on text figure 10 and the

distances there recorded. The b.v. 21.5 mm out is by our rule made the oldest and is marked no. 1. The next smaller distance is 19.1 mm and this b.v. has been marked no. 2. These larger numbers thus indicate the order of succession and it turns out to be a regular spiral with a counter-clockwise rotation. The very regular sequence and rotation of the twelve b.v.s. constituting this triangular area (but ten have been numbered in the figure) is remarkable enough to merit further consideration.

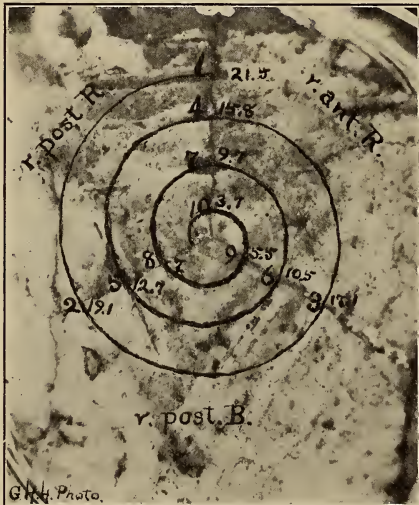


FIG. 10 View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, $\times 10$. The spiral is drawn to show the order of development of the b.v.s.

Suppose that during the nepionic stage a b.v. was developed at the point of contact of these three plates and that soon after its exit it had budded a new b.v. aborad, which also sought exit at the same point. No. 1 would be thrust orad and reach in this direction to exercise its function. The growing points of r.post.R. and r.post.B. would push by and finally surround it, thus giving it a position not at the corner but on the suture. A third b.v. seeking exit also at the plate corners might force no. 2 to the left and would itself, in seeking freedom for its function, pass to the right and thus become inclosed between the growing points

of r.post.B and r.ant.R. A new factor would now enter to determine the position of the fourth b.v. Nos. 2 and 3 would be its nearest neighbors. It would find water richer in oxygen and freer from excretory matters in the direction of no. 1. Its own effort to function to better advantage might alone insure for it a position on the suture next no. 1, but natural selection would soon fix any variation in this direction however caused. To follow the series in this manner down to no. 12 and find a probable cause for each position, is a simple matter. The evidence seems to favor the idea that the b.v.s. of a triangle are organically related to each other and are but external branches of one internal tube or chamber. There is no evidence, however, to warrant our associating the group with the circumoral ring of the water vascular system though a connection was not at all unlikely.

It is of course possible that nos. 1, 2 and 3 were independent b.v.s. and that, as the sutures were extended, each politely awaited its turn to send a branch through the point of least resistance. Such a condition could be made to speak eloquently against the idea of struggle for existence between parts of an organism, but there seems to be no evidence in its favor. An examination of the sutural faces of the plates might decide the question and free plates of this species may yet be found and examined. If the development was as at first suggested, the sutural canals should show an inclination toward a point under the plate corner and that would be the position of the larger subthecal canal or sac



FIG. 11 From a photomicrograph of a plate of a species of *Palaeocystites*, seen from the edge. The edge of a steel mm rule shows just below.

into which the b.v.s. would periodically discharge their contents. If the development and grouping was of the other type, the

sutural canals would be inclined toward a point under the middle of a plate suture and the b.vs. would discharge in this direction to reach the common tube or sac of the group. It is quite evident in text figure 3 that the triangles at the plate corners form the related groups in *Cliocrinus*. Text figure 11 will show that the sutural canals of *Palaeocystites* are inclined toward a point under the plate corner and that here also the corner groups are the related ones. Such evidence as there is then is markedly in favor of calling the triangular series a natural group and not the parallel series. The primary interradiial group just described may be considered as typical also of four others which were simultaneously developed at the orad angles of the other BB.

Development in complexity. The small portion of the cup of *Cliocrinus perforatus* shown in text figure 1 was possessed of more than 230 b.vs. This would indicate that the complete specimen possessed some 5000 similar structures. *Palaeocrinus striatus* on the other hand had a cup practically reduced to but three circlets of five or six plates each and its b.vs. were less than 150 in number. We should therefore expect to find some compensatory arrangement whereby the physiological balance of respiration might be maintained. The arms doubtless came to take a larger share of this function and so relieve the cup surface, but the latter abundantly shows that it also became adapted to carry on the same function to a greater extent than formerly. We have already seen that the oval sutural canals of *Cliocrinus perforatus* may be indicative of the movement of the free ends of b.vs. toward the plate centers or to regions of purer water. If the b.vs. could branch under the theca to give rise to new members, their branching or forking outside of the theca need not be unexpected. Any b.v. possessing a forked structure would come to hold the arms of the Y in the best functional position which would be in a line crossing the suture. Such a structure could not be easily withdrawn and protection would be first secured by making the arms of the Y lie close to the plate surface and thus changing the Y to a T. The close contact of the arms of the b.vs. with the plate surface might inhibit the formation of epistereom immediately beneath them and stimulate growth between them. Ridges so formed would be an additional means of protection and, however initiated, would be favored by natural selection.

With the necessity for occasional withdrawal removed, the arms of the b.vs. could extend with plate growth and all available plate area be used for respiratory purposes. The form might thus easily

pass from the primitive arrangement in which its b.vs. simply occupied the lines of plate boundaries to the more complex arrangement by which its b.vs. came to occupy the area of plate surfaces. It is probable that in *Palaeocrinus* the development of T-shaped b.vs. was not so simple as the processes above outlined. The youngest b.vs. found in the type are already a little distance from the corners and appear as small low mounds that sometimes show more on one side than the other. It looks as if free or uncovered external b.vs. had already been suppressed and that the extension to the surface did not break through the epidermis, but lifted it as a mound which became elongated with the growth of the plate and under which the b.vs. extended their arms. As several layers of tissue are involved in these body wall extensions, the outer layer or the next layer under this might form porous stereom and the deeper layers form the walls of a contractile tube free to move inside of its rigid but porous covering. Evidence of additional (abnormal) forking is shown in plate 5, figure 4. Both of the epithecal canals below the longest are distinctly double near the suture but are single in their earlier portions. At least three b.vs. here came to empty into a single sutural canal. One arm of the first fork evidently tried to repeat the process.

The b.vs. as indexes of plate growth. Could we determine the rate or regularity of b.v. development we could use the position of these structures as indexes of the relative rapidity of plate growth during different ontogenic stages. If the new b.vs. appeared at regular time intervals their distance apart on any suture would be in strict proportion to the rate of plate extension. Text figure 11 may be made to offer an illustration. The measurement of position of the b.vs., in part recorded in the figure, is as follows:

Table 2

1 21.5 mm	4 15.8 mm	7 9.7 mm	10 3.7 mm
2 19.1	5 12.7	8 7.0	11 2.5
3 17.1	6 10.5	9 5.5	12 1.0

From the measurements of position recorded in table 2 we have deduced the following table of distances between one b.v. and the next younger on the same suture.

Table 3

1 to 4 = 5.7 mm	4 to 7 = 6.1 mm	7 to 10 = 6.0 mm
2 to 5 = 6.4	5 to 8 = 5.7	8 to 11 = 4.5
3 to 6 = 6.6	6 to 9 = 5.0	9 to 12 = 4.5

The first vertical column gives the distance of each member of the first triad from the corresponding member of the second triad, or from that member which came to occupy the next position on the same suture. The second vertical column does the same for the distances between the second triad of b.vs. and the next three b.vs. to appear. The first horizontal line of figures gives the distances for the vertical suture, the second line gives them for the diagonal suture at the left and the last line gives them for the diagonal suture at the right. Interpreted according to the above assumption, the distances indicate that the most rapid growth was after the development of the first triad and between the times of the fixing of b.vs. 3 and 6 on the same suture. This would be during adolescence. The marked decrease next the end of the series would indicate that the specimen was practically fully grown or mature. By measuring these distances on a number of different areas and using averages one could plot a curve representing this variation of plate extension in time and the character of such a curve in itself would be good evidence that our assumption was not far wrong.

The b.vs. speak still more clearly of variation of rapidity of plate extension in certain directions. Suppose we ask if the elongate form of the species has been brought about by adding stereom more rapidly to the orad and aborad sutural faces of the plates than to their lateral sutural faces. We may question text figure 10 concerning this matter. The average distance apart of the b.vs. from 2 to 8 (on the right aborad suture of r.post.R) is 6.05 mm; from 3 to 9 (on the left aborad suture of r.ant.R) it is 5.80 mm. Averaging the two we obtain 5.925. On the vertical suture from 1 to 10 the average is 5.933 mm. The difference here is so remarkably little that it would be unwise to use it as the basis of a declaration that the vertical elongation of the aborad half of a R. was in excess of the lateral extension of one side. We shall soon find, however, that the plates of the two lower circlets give very decided evidence that vertical extension was in marked excess of lateral. We may also note here that r.post.R seems to have added stereom to its right side a little more rapidly than r.ant.R did to its left. This point will be again referred to when we come to discuss the lateral extension of the theca.

The aborad radial groups. We have so far given particular attention only to one of these groups of b.vs. which developed about the orad angle of each B. These groups are interradian in posi-

tion. A group of b.v.s. was developed at the orad angle of each IB and a group also at the aborad angle of each R. These ten additional groups are all radial in position. To distinguish between them we shall call one series orad and the other aborad. Text figure 12 shows two of these groups, an orad radial group around the aborad angle of a R and an aborad radial group around the orad angle of an IB. The latter group will now receive our attention.

The members of this group occupy a triangular area and are numbered from 1 to 9. The evidence here is for regular serial formation with counter-clockwise rotation as in the interradial group. For instance, we have three b.v.s. on the left upper shoulder of the IB and but two on the right. The distance of 2 from the apex of the IB is greater than that of 3, and the distance of 5 is greater than that of 6. In

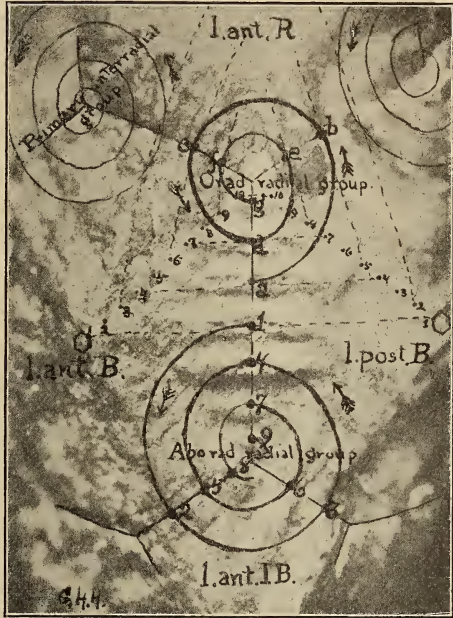


FIG. 12 View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, x10. The spiral lines are drawn to indicate the order of development of the b.v.s.

table 4 we have entered the measured distances of all these b.v.s. from the point in question, arranging those of each suture in a separate vertical group as below.

Table 4

1	1.8 mm	2	1.25 mm	3	1.15 mm
4	1.3	5	.7	6	.6
7	.75	8	.3		
9	.3				

These distances have been plotted in figure 12 and a spiral line drawn through them to more clearly express their serial formation and its direction.

We may now turn again to the questions of variation of rapidity of plate extension in time and in direction. Taking the distances between one b.v. and the next younger on the same suture and arranging as in table 3, we have

Table 5

1 to 4 = 0.5 mm	4 to 7 = 0.55 mm	7 to 9 = 0.45 mm
2 to 5 = .55	5 to 8 = .40	
3 to 6 = .55		

When we compare these b.v.s. with the interrādiā group just studied, we find that they are fewer in number and the distance separating the oldest two on any suture is also less. Were the time intervals regular for b.v. branching, we should have to concede that this group is a younger group and the shorter distance between its oldest members, as shown in table 5, would tend to corroborate this view. We might then be led to believe that the new series was developed from an early branch (perhaps the first) of the older interrādiā series when the two b.v.s. would have been separated by the very short distance across an angle of the young plate. We shall do well, however, neither to accept nor reject the idea if our mind can thus hold judgment long in suspension. We may also note that the younger b.v.s. on a suture are nearer together than the older and this again we may interpret as due either to a more rapid formation of b.v.s. near maturity or to diminished speed of stereom formation. The latter explanation seems the more probable to the writer.

We take up again the question of difference in rate of plate extension in direction. From our study of the relative positions of the b.v.s. in one of the primary interrādiā groups we were forced to conclude that the building of stereom on the aborad sutures of the radials was but little, if any, in excess of the building on the lateral sutures of those plates. With equal growth on all sutures of a hexagonal plate there would be no change in plate form. The radials of a mature *Palaeocrinus* have much the same form as the radials of a very young specimen, at least so far as concerns that portion which lies to the right, left and below the center of the original plate. With the group now under consideration (an aborad radial group) there is evidence for marked difference in rapidity of plate extension in direction.

In order to present this evidence more clearly and to show its bearings on change in plate form during ontogeny, we have formed

a new table (table 6) in the following manner. The distance of b.v. 1 from the orad angle of the IB as measured on the vertical suture of figure 12 (1.80 mm) has been used as a minuend; the distance of the b.v. 2 from the same point or angle of the IB (1.25 mm) has been taken as a subtrahend; the difference between these numbers, the remainder, (0.55 mm) has been entered as the first member of the new table. Taking b.v.s. 2 and 3 and treating them in the same manner, we obtain a remainder of 0.10 mm and enter this as the second member of the table. The other differences expressed in the table were found in a similar manner. The two numbers before any sign of equality designate the b.v.s. whose distances (from the orad angle of the IB) were used for minuend and subtrahend.

Table 6

Giving, for an aborad radial group, the difference between distances from the orad angle of the IB (expressed in mm) of a b.v. on the

vertical suture and the next b.v. to appear	left diagonal suture and the next b.v. to appear	right diagonal suture and the next b.v. to appear
1-2 (1.80-1.25) = 0.55	2-3 (1.25-1.15) = 0.10	3-4 (1.15-1.30) = -.15
4-5 (1.30-.70) = .60	5-6 (.70-.60) = .10	6-7 (.60-.75) = -.15
7-8 (.75-.30) = .45	8-9 (.30-.30) = .00	

To quickly, clearly and visually explain table 6, let us take a hypothetical orad radial group. The b.v.s. are to appear in sequence with a time interval that shall be the same for all. The addition of stereom to the aborad sutures of the basals are supposed to be constantly and regularly in excess of the amount added to their common vertical sutures. This will result in increasing the length of the plate more rapidly than the width. Let us suppose the ratio between verticle and lateral rate of extension to be as 4 to 3. Then when b.v. 1 has increased its distance from the orad apex of an IB by 4 units, b.v. 2 will have increased its distance by only 3 units.

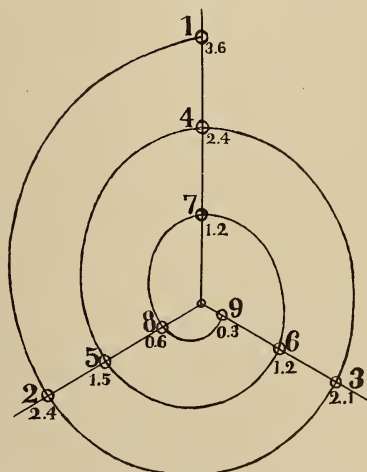


FIG. 13 Drawn to represent the b.v.s. of a hypothetical group in which the ratio of vertical to lateral growth is as 4 to 3

Figure 13 shows the condition of things when the tenth b.v. has just appeared at the orad apex of the IB and b.v. 9 is just 0.3 millimeters distant from the same

point. If now we construct a table after the manner of table 6, but using text figure 13 for the basis, we shall have the result here given as table 7. A comparison of the two tables will speak eloquently for our contention.

Table 7

1-2 (3.6-2.4) = 1.2	2-3 (2.4-2.1) = 0.3	3-4 (2.1-2.4) = - . 3
4-5 (2.4-1.5) = .9	5-6 (1.5-1.2) = .3	6-7 (1.2-1.2) = - . 0
7-8 (1.2- .6) = .6	8-9 (.6- .3) = 3	

We shall find that the ratio between lateral and vertical extension varied during development. Between the appearance of b.v.s. 1 and 4 the vertical suture of this group increased 0.5 mm in length. Between the appearance of 2 and 5 the left diagonal suture increased 0.55 mm. Lateral extension appears to have been slightly in excess of vertical at this time. They soon become equal. Between the appearance of 5 and 8 the lateral expansion was only 0.4 mm. At this period of growth the ratio between vertical and lateral extension seems to have reached the ratio of 11 to 8.

A study of the basals as presented in the cup analysis and in the photograph will show that this ratio is not far out of the way, but it must be remembered that it is not for the whole B but for the lower part of it and that the ratio is one that changes all along the edge of the vertical suture, the most rapid addition being at the top of this suture where it practically equals the rate of addition to its orad sutures and the least rate being at the bottom or aborad end of the same vertical suture. This growth ratio clearly indicates that very young plates were no longer than wide or, in other words, that they were practically symmetrical and so suggestive of cystidean plates. With the aid of this ontogenic evidence we have attempted to present the probable outlines of two young or primitive plates in text figure 9.

It is interesting to note that this increase of vertical plate extension had carried b.v. 7 so far from the apex of the IB at the time of the emergence of b.v. 9 as to offer the latter as much freedom, apparently, on the suture occupied by b.v. 7 as on the suture occupied by b.v. 6. The irregular position of b.v. 9 in figure 12 is thus seen to be in harmony with our suggested physical reason for rotation and to rather strengthen that hypothesis, for heredity should have placed this b.v. next to no. 6. The position occupied by b.v. 9 in this group is not normal for all of the other IBB possess a third b.v. on their right-hand upper sutural faces with the possible, though not probable, exception of l.post.IB. The upper edge of this plate has been so badly damaged that an accurate count is

not possible, but its width suggests the presence of a third b.v. The measured length of the upper right-hand sutures of the IBB is as follows: l.post.IB 2.2 mm; r.post.IB 2.2 mm; r.ant.IB 2.0 mm; ant.IB 1.7 mm; l.ant.IB 1.6 mm. An additional reason for the choice of the vertical suture by our aberrant b.v. 9 may be here seen, as what should have been its normal suture offered it the least room for the exercise of its function.

The oral radial group. Text figure 12 shows a triangular area of b.v.s. developed around the aborad apex of l.ant.R. In order to avoid confusion we have used letters to designate the members of this group. As these were developed at the upper right-hand corner of l.ant.B., their places of origin on the plate must occur along a line connecting the primitive plate corner with the present plate corner. This line is represented by a series of ten equidistant and numbered dots. The upper left-hand portion of l.post.B. has been treated in the same manner and it must be seen that the position of any dot of either series, was, at some time during growth, identical with that of the similarly numbered dot of the other series. B.v. *a* did not appear until the plate had attained about one-third of its present diameter, or until the plate corners had reached the position of dot 4. B.v. *d* appeared when the plate corners had reached dot 7 and b.v. *g* when the plate corners had reached dot 10. The extension of b.v. *e* suggests dot 8, while *f* would correspond well with dot 9. This indicates a counter-clockwise rotation for this group.

We must note that the correspondence is not exact and exactness should not be expected where rate of growth is compared with a hypothetical mathematical schedule. The diagram, however, contains some errors. First its dotted "lines of origin" are a little too long and bring b.v. 1 of the aborad radial group in line with the upper ends instead of the lower ends of the common suture of the BB. Second, the line should be a curved line and not a straight one as the plate is not flat but convex. Equidistant dots on a curved surface would no longer be equidistant when reproduced on a photograph of that surface. Third, the plate center is in itself a point which can not be located with exactness. This form of diagram has been used for its suggestiveness and its simplicity. Another manner of approach would have been through extending b.v.s. *a*, *d* and *g* to the "line of origin" and then dividing these portions of the line into three equal parts.

We may, however, strengthen our suggestion of counter-clockwise rotation for this group by using the measured distances of

the b.v.s. from the aborad angle of the radial. These are presented in table 8.

Table 8

$a = 1.3$ mm	$b = 1.00$ mm	$c = 0.90$
$d = .8$	$e = .55$	$f = .35$
$g = .35$	$(h = .15$	$i = .14 ?)$

Using these to form a table after the pattern of table 6 we have

Table 9

$a-b$ (1.30—1.00) = 0.30	$b-c$ (1.00—.90) = 0.10	$c-d$ (0.90—0.80) = 0.10
$d-e$ (.80—.55) = .25	$e-f$ (.55—.35) = .20	$f-g$ (.35—.35) = .00

This also shows the more rapid vertical extension of the BB. We may again note that the difference between the rates of vertical and lateral plate extension is not so great here as in the lower area of this figure. In other words, the vertical extension of the aborad portion of a R was very nearly as rapid as the vertical extension of the orad portion of a B. The portion of b.v.1, so near the center of the vertical suture, shows also that stereom formation was but little more active on the aborad sutural faces of the BB than on their orad. The greatest difference in growth rate was along the vertical sutures and the modification of form was brought about by decreased or inhibited growth aborad rather than by increased growth orad.

Infrabasals. The absence of the formation of b.v.s. at the aborad angles of the BB is correlated with a very marked lack of stereom formation along the common sutures of the IBB. The first b.v.s. to extend their arms over the IBB once occupied nearly central positions on the orad shoulders of these plates. Had stereom extension occurred equally at the right and left of these b.v.s. they would have retained their central positions, while now they are close to the outer edges of these shoulders. At the time of protrusion of b.v. 2 (see text figure 14) it was about 0.3 millimeters distant from a vertical line bisecting the plate and continuous with the suture between the IBB below it. Following the external canal down to the suture we find that the opening to the interior was 0.5 millimeters distant from the same line at death. The difference of 0.2 millimeter represents the widening which has taken place on this portion of the B during the last three-quarters of its growth. This very slight divergence of the two longest b.v. extensions on a B offer a valuable character for

use in recognizing the BB of this species and in orienting them. Looking for the earliest position of this b.v. on the IB we find it close to the point marked *a* and about 0.6 millimeter distant from the suture. This older portion of the IB has added but 0.3 millimeter to its side, while it has added 2.3 millimeters to its orad sutural faces. In other words, the rate of stereom addition to the orad sutural faces was nearly eight times as great as was the rate of addition to the lateral sutures of the plate.

The growth has not only been slight between the IBB, but it has not extended to the outer surface of the plate. The result is a well-marked groove widest next to the orig-

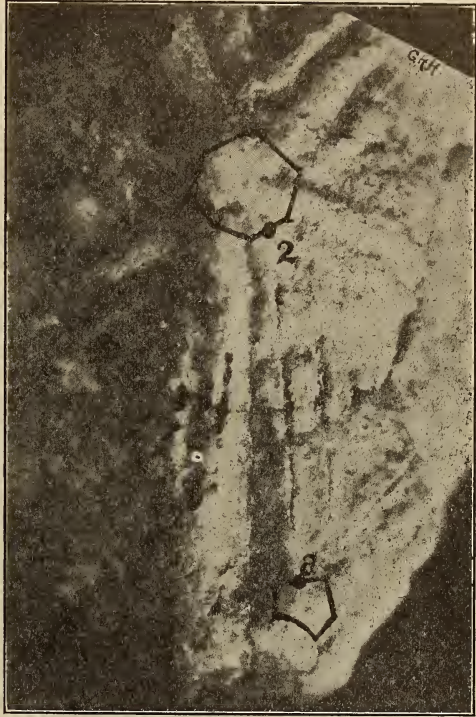


FIG 14. View of a portion of the holotype of *Palaeocrinus striatus* Billings. From a photomicrograph, x10, and showing r.post.B., r.post.IB. and r.ant.IB. The probable forms of two of these plates at an early stage in their development are shown in outline.

inal position of the proximal stem joint and becoming gradually narrower and less deep orad. The groove is very smooth and shows only faint vertical growth lines. This lack of growth at the suture has left its impression on the B and has caused the groove to be carried orad on the latter nearly to its center. The B has kept a record of the cross section of the groove, as it appeared at the suture, from its earliest stages to the time of death. This very characteristic feature of a *Palaeocrinus* B, together with the slight widening of the oldest aborad b.vs. (already mentioned) will be referred to again under our remarks on *Paleocystites chapmani* Bill. Using the different growth rate with reference to direction, we have outlined a young IB in text figure 14. It approaches somewhat the character of a stem joint in that it is wider than high and has no b.vs. on its lateral sutures.

Making a general review of the differences in rate of growth already recorded we may say that the vertical element was strong throughout the three circlets of plates, except on the orad ends of the RR and the aborad ends of the IBB, but that the lateral element was exceedingly weak near the proximal stem joint and gradually became stronger on ascent of the cup. At the base of the arms it very nearly equalled the rate of the vertical element. The cup thus received its present fusiform character.

The orad interradial series. There remain five b.v.s. not yet accounted for and these apparently had their points of origin at the orad ends of the sutures between the RR. Each member of the

FIG. 15

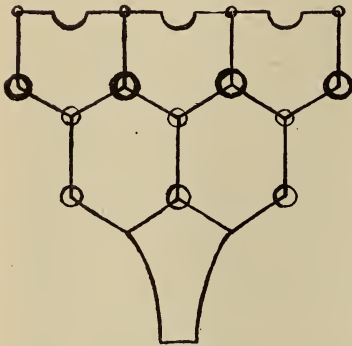


FIG. 16

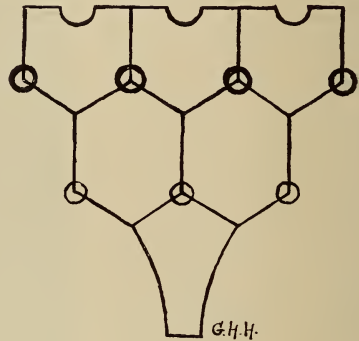


FIG. 17

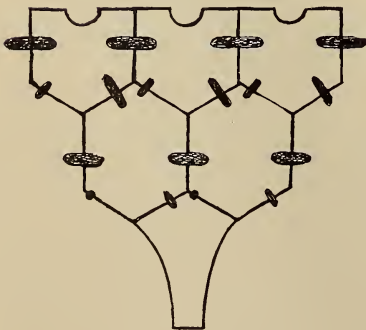
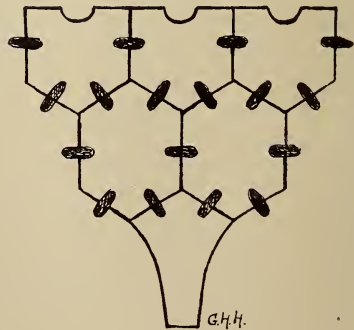


FIG. 18



series seems to have had no room for further development but the position is so close to the arms that the series may be connected with the more elaborate respiratory system of the latter.

Relations of the b.v.s. The relations of the four classes of groups as we have interpreted them may be shown by text figure 15,

in which the size of the dot at the supposed points of origin is made commensurate with the importance or age of the group. If the orad radial groups and orad interrarial series were developed as branches of one of the others, a still more primitive form would be represented by text figure 16. As soon as each b.v. of figure 16 had given rise to two other b.vs. we should have a condition like that shown in text figure 17. At about this stage we may suppose that the initial members of the orad radial and orad interrarial series made their appearance.

The possibility of a primitive or nepionic stage like that shown in text figure 18, where these b.vs. may be supposed to have appeared simultaneously and not at the angles but on the middle of the sutures, should perhaps not be dismissed from mind. In this case new b.vs. would be formed by branches, simultaneous or alternate, on each side of these and also on the sutures, if the first were so formed. There would be as many natural groups as there were sutures in this case and we should have no difficulty in accounting for the upper young members on the common sutures of the radials. A form like this appears rather complex for a beginning though even here we might credit acceleration with changing a primitive series of three into a simultaneous group of three and credit natural selection with the placing of such a group at the middle of the sutures where it could function to best advantage and not interfere with new members protruded at the corners. These oldest b.vs. are, however, not now on the middle of the sutures, but differences in rate of growth might have displaced them. It has seemed to the writer that the evidence from this form and also that from *Cleiocrinus* is on the whole strongly against the latter view. Utilizing a recommendation of the late Professor Rowland, we may keep both hypotheses in mind, but for the present may give the former a position of from 80 to 95 points of credibility on our mental sliding scale of 100 and wait for the evidence yet to come from future research.

Growth lines. The plates so far discussed all show minute growth lines, but these are only noticed between the ridges. On finding a plate in which the canal coverings had been worn away and the number of ridges therefore doubled, we might be able to use this character to aid in distinguishing between the canal bottoms and the true external plate depression between the canals. The canal floors would show no growth lines.

The radianal. In normal plate development the plate angles occur where there is least resistance to plate extension or at the

boundaries between neighboring plates. In other words, two sutures meet to form an angle at a point which lies in one extremity of a third suture. Plate 6 figures 1 and 2, show that our radial forms no exception to the law though it has a rather rounded outline which at *a* is so marked and further intensified by the prominent middle epithelial canal from r.post.B as to give it the appearance of possessing a fifth angle. The plate is, however, essentially quadrangular, as in *Porocrinus*, and was truly so in its early neanic stages. Bather's figure, already cited, makes the projection at *a* one of the angles of the plate and places additional ones midway of each of the other three sutures bounding the plate. Not one of the angles so drawn meets a third suture in the figure he has used. In addition to these erroneously placed angles, the true upper and lower angles of the plate were recognized, thus making it hexagonal. The angles at the junction of r.post.R with r.post.B and that at the junction of *x* and post.B were not seen. The mounting process has, however, made these clearly visible in the untouched photograph used for plate 6, figure 2. The rounded surface of the plate makes the sutures appear as meridians viewed from the side. With the sutures in the center of the field of view they show more nearly as straight lines and, with the exception of the aberrant suture next r.post.B, they have been so represented in text figure 4. Even this suture becomes a nearly straight line when viewed as in text figure 5.

The epithelial canal passing on to this plate from r.post.B has had its covering and a good portion of the sides removed. The floor of this canal may be distinctly seen in plate 6, figure 2, lying to the right of a wide portion of its left wall. Where it is broken or cut off at the radial end, there is a black patch that represents a limonite mud-filled basin which occupied this left canal wall and opened into the canal itself by a smaller pore. This same figure also shows a series of such limonite mud-lined or filled basins along the left side of the strong exothecal canal which runs from r.post.B over r.post.R. The pit shown in plate 6 figure 2 *b* is so definite, so well lined with limonite-colored mud and afterward filled with calcite that it challenges attention. Many similar pits are suggestive of protected side water pores opening into the canals, but the structures are so irregular in arrangement and so large a portion of them may be due to differential solution or other erosive process that they will be dismissed with this mention. Another very definite structure that is perhaps connected with respiration may also be mentioned here. It is found close to the plate angles and is in the form of two very

small depressions, one on either side of the suture. A portion of the plate between a pit and the suture is distinctly raised. Plate 5 figure 4 shows a pair of these near the lower end of the suture between r.ant.R and r.post.R. They are suggestive of end openings to young canals, but they are difficult structures to photograph and will also be dismissed with this brief notice of their presence.

Lateral extension of the theca. Text figures 5 and 6 show a somewhat marked antero-posterior flattening of the species that is but very slightly due to compression by overlying deposits. Text figure 19 shows a view of the proximal ends of the IBB and the im-

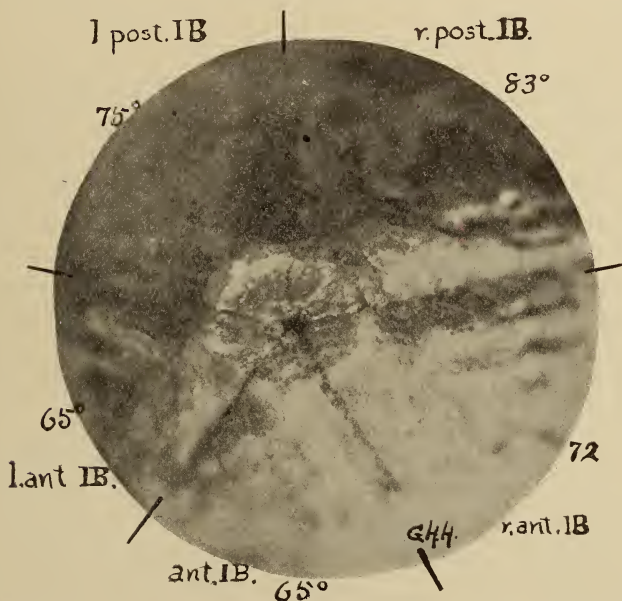


FIG. 19 Proximal end of *Palaeocrinus striatus* Billings. From a photomicrograph $\times 10$. The angles indicated are those of the ends of the sutures nearest the proximal columnal. The figure shows clearly the five depressions due to inhibition of stereom formation on the lateral sutures of the IBB. This is most pronounced opposite the oldest portions of these plates. The r.post.IB carries a good cast of one of the sutures of the proximal columnal.

print of the proximal stem joint, which in two places clearly shows the imprints of its sutures. There is no evidence for a pentagonal column. The flattening of the theca is manifest even here and the first columnal was an oval and not a circle. On extending the sutures shown in this figure and measuring the angles between them, it will be seen that l.post.IB and r.post.IB together take up 158° of the posterior side of the column, or 14° more than their share. There can be no question here but that we are dealing with differences due to growth. The l.ant.IB came on one edge of the fold and is the

smallest plate in the figure. The fold on the other side came between r.post.IB and r.ant.IB and both of these plates are larger than the others and have undergone excessive widening at their orad ends. The variation in rate of growth in this part of the theca is shown by the following table:

Table 10

	Height	Length of two orad sutures
r.ant.IB.	3.8 mm	4.2 mm
ant.IB.	3.5	3.3
l.ant.IB.	3.5	3.2
l.post.IB.	3.6	3.9
r.post.IB.	3.7	4.4

Just above the place of most rapid growth lies r.post.B and this plate is quite distinctly folded vertically. Had this folding been due to compression after death, the RA would show signs of displacement. Instead of this it shows the peculiar extended growth to the right which gave it the appearance of possessing a fifth angle. The folding and bowing out of the center of r.post.B which is still further accentuated by its central knob, is readily seen in text figure 6 and is therefore normal to the species. This compression reminds us of the more markedly folded plates of the Anomalocystidae, but our theca is compressed at right angles to the plane of the thecal apertures and not in this plane. With five basals, but one would be subjected to this folding. On examining these BB for postmortem changes, we find only a very slight disturbance of r.ant.B and this is shown in text figure 8. We may now recall the evidence found on p. 228 where it was shown that r.post.R had been adding stereom to its right side more rapidly than r.ant.R had to its left.

The tegmen and plates above the anus. This region is taken next for the purpose of completing the evidence for flattening during ontogeny. The series of plates over the anus form a long line in which the madreporite is the most prominent, but plate 7, figure 2, shows that none of these plates have been displaced and their sutures show that no shortening of this line was possible. The widened anal area has so thrust the arms away from it as to cause those of l.post.R and r.ant.R to lie almost opposite each other. This may be seen in plate 7, figure 1. The five food grooves do not run to one center but clearly express the hypothetical primitive food grooves with the forking of the right and left rays (see Bather, op. cit. p. 11). L.post.O and r.post.O have an acute angle at their

orad ends while l.ant.O and r.ant.O have widely truncated ends. The openings between the orals to admit the visceral extensions of the arms are relatively large, but orad of these the orals meet and thus form a very solid or strong tegmen. The only evidence for displacement to be found in this figure is the slightly disturbed position of the upper edge of ant.R.

The ambulacra pass over the edges of the orals and are small and irregular. Still more irregular, and larger, are numerous interambulacra. These are best seen in plate 7, figure 2 above the madreporite, but show also for l.post.R.

The anal, X. The anal plate is fully as wide as the smaller radials and we have therefore six subequal plates surrounding the tegmen. This should make room for the development of a sixth member of the orad radial series of b.v.s. There seems to be evidence for such a group, as may be seen by a study of the first three figures of plate 6, but there is at the same time a concomitant and marked weakening of the group which should have developed normally at the aboral angle of r.post.R. For instance, no b.v.s. to represent a group here have been added to the suture between r.post.B and r.post.R. Cross sections of a few sutural canals can be detected between RA and r. post. R, but they seem to be poorly developed and of very small diameter. The group has but one strong member to represent it and that is the oldest and central b.v. on the suture between r.post.B and RA. It should be noted that this b.v. represents the first formed of the series whose initial position would have been at the aboral angle of r.post.R and this position has been accorded it in text figure 3. There seems to be evidence here that a branch from this group made an early exit at the aboral angle of x and, by developing there, practically stopped further development at the original position. If we may so interpret the evidence, we have nothing to disturb the fundamental pentamerism so clearly marked in all other places.

If these groups of b.v.s. were connected by subthecal canals which in turn were connected with the circumoral canal of the water vascular system and these canals should run so close to the under surface of the thecal plates as to become attached to them, we should find markings present so remarkably like the "*hydrophores palmès*" which Barrande discovered in *Aristocystites*, *Pyrocystites* and *Craternia* that we must hesitate to accept Neumayr's suggestion

that they are subtegmina food grooves and believe with Barrande that the structures are respiratory in their nature.

Endothecal structures. An examination of plate 6, figures 1 and 2, will reveal another reason for the difficulty heretofore found in determining the position of the sutures bounding RA. The undercutting of the specimen to remove it from its bed removed also so much of RA and X as to carry away nearly all of the common sutural edges of these plates. This suture was 2.8 mm long, but all that remains of it is .25 mm next to r.post.R and about the same next to post.B. It could not be seen because nearly five-sixths of it had been removed. The cutting had not only carried away nearly all of the surface of these plates but it had also penetrated beneath the plates and exposed a little over four square millimeters of the interior. This area, the greater part of which is immediately under the stereom of x, is of peculiar interest for it displays markings in carbonized lines which appear like sections of a network of tubes having a diameter of about 0.2 mm. When first noticed, it appeared as if we had here the remains of a colony of Bryozoa but so soon as it was discovered that these structures were not on the surface of the plates, but beneath them, they received more careful examination.

In plate 6, figure 3, we have marked a sutural canal *c* and at the extreme right-hand side of the figure there is a broken piece of r.post.R with an angle of the crystalline calcite resting on the suture. This angle, which is marked *d*, may be seen in all four figures. If now on figure 1 of this plate we place a millimeter rule tangent to the under surface of the sutural canal designated as *c* and let the edge of the rule run by the lower angle of the broken calcite designated as point *d*, we shall have a line 58 mm long which will afford us a good basis for study and comparison of the figures. Resting on this line and 28 mm out from the sutural canal *c* we find a dark triangular area with a base of 2 mm. Below this are three parallel tube sections which together occupy a width of 6 mm. Tubes also lie against the other two sides of the triangle, but a series parallel to these is not detected. The tube sections here display rounded ends showing the sections to be in part longitudinal and in part tangential. In other words, the tubes were curved. Outside of this area the sections approach more closely the character of circles and it is apparent that we are here dealing

with cross sections of tubes belonging to the same system. As to the character of these marks we must note that the boundaries show only as carbonized lines and spaces in places made more distinct by an internal tube lining of limonite-colored mud. There are no distinct walls as in sections of bryozoan colonies.

The fact that these tubes are commensurate in diameter with the sutural canals would lead one to question as to whether or not they were internal continuations of the exothecal canals. The fact that they contain limonite-colored muds would negative this idea, for we have supposed that b.vs. contain coelomic or other body fluids and not sea water. The idea is also negatived by the direction taken by the tubes, their curved character, and their great number.

Another hypothesis is open for us. We have seen that the conditions of existence favored a system of anal respiration. Such a system would favor saclike extensions of the rectum that would tend to become branching diverticula and so form respiratory trees very like those possessed by Holothurioidea. These might be either homogenic or homoplastic. As the specimen died with the anal area down, the intestine would press any structure between it and the plate against the latter. In this case we should find portions of the supporting tubes on their sides and variously bent. Surrounding these would be a border of tubes whose tips only touched the inside wall of the anal plate and these would give us the cross sections we find. These tubes would contain more or less of the limonite-colored muds of the bottom, drawn in by the last respiratory efforts of the creature as we found them drawn in in *Blastoidocrinus*. This limonite-colored mud is most often very suffuse and only faintly apparent. In other places it has collected as little lumps but always in the tubes. The tube walls are very poorly preserved and appear as if partly ruptured or decayed. Their soft walls were often compressed, thus making them present angular outlines.

Through the courtesy of the late Doctor Whiteaves the writer was allowed to develop this portion of the specimen. From 0.1 to 0.2 mm of this surface was removed with a fine narrow file and the area photographed again under the gum dammar mounting and with an amplification of 10 dia. The result is shown in plate 6, figure 3. Another thin sheet was removed, but in order not to destroy any of the sutures next r.post.R it ran from a thickness of 0 mm on the right to between 0.1 and .2 mm on the left. The uncovered

area was thus extended slightly toward the left. A new photomicrograph was now made and a colored screen used in order to show if possible the limonite-colored mud fillings. This photomicrograph is reproduced as figure 4 of plate 6. The subject is a difficult one both for photography and for reproduction, but it is hoped that the plate will present enough detail to be both of interest and value.

Palaeocrinus chapmani Billings

Palaeocystites chapmani Bill. Canadian Org. Rem. Dec. III, p.71-72. No figure.

The description of *P. chapmani* given by Billings in no particular differentiates that species from *P. striatus*.¹ The term "radiating ridges" is not used by him to designate either the covered epithelial canals or the side walls of the latter when the covering is removed, but is used simply to designate the larger and more general relief features of the plate. Thus one of the "radiating ridges"

¹"Description. The few plates of this species that have been collected exhibit the peculiar character of the genus in a most interesting and satisfactory manner. Without being acquainted with the structure of the plates, the observer would almost unhesitatingly refer them to two very distinct species, so great is the change in their appearance produced by the wearing away of the external surface. The perfect plates resemble those of *P. dawsoni*, inasmuch as the number of radiating ridges is the same as the number of sides. The ridges are however of a different form. In *P. dawsoni* they are narrow at the base, and the space between them is flat; but in *P. chapmani* they are broad at the base, or roof-shaped, the base of each spreading out to a breadth equal to that side of the plate to which it extends. A perfect plate of this species, for instance one of six sides, may therefore be described as presenting six furrows radiating from the center to the six angles, these furrows gradually increasing in depth and width as they recede from the center of the plate. Or it may be characterized as exhibiting six roof-shaped ridges radiating from the center to the sides, and increasing in height and width at the base as they approach the side.

When, however, the external surface is worn away, the plates assume a very different appearance. They then become covered with deep fissurelike striae, like those of *P. tenuiradiatus*, to which they bear so close a resemblance, that to the unpracticed eye, they appear to be the same. They can always, however, be distinguished by this character. The ridges or partitions between the fissures, which terminate at the centers of the sides of the plates, are the highest, those at the angles being the lowest; but in *P. tenuiradiatus* it is the very reverse; the angles of the plate are more elevated than the centers of the sides."

of his *P. chapmani* (see upper left-hand region of text figure 20) consists of a long, high, large, central, covered epithelial canal with the younger, shorter and smaller canals grouped on either side of it. These all crossed the suture and so form a ridge "broad at the base, or roof-shaped." The canals themselves Billings calls "deep fissurelike striae" and, as shown by our figure, a "radiating ridge" may consist of a group of seven or eight of these fissurelike striae. His whole description, given in the footnote, tells us only, so far as concerns the description of the species, that it exhibits "six roof-shaped ridges radiating from the center . . . and increasing in height and width . . . as they approach the sides. When . . . the external surface is worn away, the plates . . . become covered with deep fissurelike striae, like those of *P. tenuiradiatus*." We may express the essence of the description as follows: the plates of *P. chapmani* show as many radiating groups of covered canals as there are angles to a plate. The older, central canals are higher and longer and from these we may pass down a regular slope



FIG. 20 From a photomicrograph (x10) of the holotype of *Palaeocystites chapmani* Bill., now in the Museum of the Geological Survey of Canada at Ottawa

to the smallest and shortest canal which is always situated next to the angle of a plate. His means of distinguishing between his *P. chapmani* and *P. tenuiradiatus* Hall is but a means of distinguishing between his *Palaeocrinus striatus* and Hall's *Palaeocystites tenuiradiatus*.

The holotype consists of a single plate so badly weathered as to lose some portion of the entire surface and very much of that surface as the plate margins are approached. A small portion of the sutural faces is also lost. If we examine in detail the figure of the type, here given, we may note the following resemblances to the *ant.B* of *Palaeocrinus striatus*.

Table II

<i>Palaeocrinus striatus</i> r.ant.B (text fig. 8)	<i>Palaeocystites chapmani</i> (text fig. 20) ¹	
No. of b.vs. crossing common basal sutures	7.	8.
“ “ left orad suture....	7.	7.
“ “ aborad suture..	3.	4.
Distance apart (at suture) of oldest b.vs. crossing to IBB.....	0.7 mm	0.8 mm
Dist. from orad to aborad angle.....	5.6	5.8
“ across at orad ends of common sutures	4.8	4.3
“ “ aborad ends of common sutures	3.1	3.2
Length of left common suture.....	3.7	3.5

In addition to the tabulated resemblances it may also be seen:

1 That the two longest and largest epithelial canals passing aborad have no younger canals between them.

2 That in *P. chapmani* we have the divergence of these canals and the peculiar groove between them which we found in figure 14.

3 That of the primitive canals the most prominent on *P. chapmani* are those passing orad or over to the probable RR of this species, the next in prominence are those passing aborad or over to the probable IBB, while the least prominent are those passing over to the neighboring plates of the same circlet or to the BB. This relation is the same as that expressed by the B of *P. striatus* shown in text figure 12.²

When we note how much the BB of *Palaeocrinus striatus* differ from each other, we must say that the correspondences noted above very strongly suggest the idea that in this type of *Palaeocystites chapmani* we are dealing with a single basal of *Palaeocrinus striatus*.

As *P. chapmani* appears to have its nearly horizontal canals a little closer together than *P. striatus*, and as the upper "radiating ridges" of Billings's description seem more raised and rounded and the depression between them somewhat deeper than in the type of *P. striatus*, we may for the present retain Billings's name and know his type as *Palaeocrinus chapmani* until additional specimens are found.

¹ The poor state of preservation of the plate of *P. chapmani* has no doubt rendered some of these measurements inexact, but the error can hardly be greater than 4 per cent.

² This relative prominence apparently expresses relative age, though the lessened rate of stereom formation along the common sutures of the BB might make the primitive b.vs. crossing these sutures appear younger than the first b.v. to cross to an IB.

Genus **PALAEOCYSTITES** Billings

Can. Org. Rem. Dec. III, p. 68-69

Palaeocystites dawsoni Billings

Can. Org. Rem. Dec. III, p. 70-71

As this species has some valuable evidence to offer concerning the question of respiration and as it allows the cystids to be better represented in our discussion, we will give it a somewhat detailed description and admit its testimony.

Size, form, etc. The more perfect specimen of the two syntypes in the collection of the Geological Survey of Canada at Ottawa is 18 mm long and about 10 mm in greatest width. The upper half is somewhat cylindrical with a hemispherical top, the lower half is obconic and tapers very regularly to a diameter of 2.5 mm. This specimen is illustrated by text figure 21 and is here designated as Syntype A. The following quotation from Billings's description is evidently a reference to it: "The largest specimen collected is a fragment of the lower half and indicates that the length of the body was about one inch, its greatest diameter being half an inch."

It should be noted that, while Billings called this syntype "a fragment of the lower half," yet he found it complete enough to enable him to determine the length of the species. As he left it, no portion of the orad end was visible, it being heavily covered by a colony of bryozoa, and the side uppermost in the bed had but one plate sufficiently weathered to remove a portion of its surface (see fig. 30).

Removal of the incrustation for some distance around this seems to show that we

are dealing with a nearly complete specimen and one in which the epithelial canal coverings were well preserved. The specimen has the crystalline calcite of its plates broken and shattered on one side, caused by its removal from its bed, and a piece broken from its opposite side which was afterward replaced. These in-



FIG. 21. *Palaeocystites dawsoni*
Bill. Syntype A. x3. Scale in mm

juries have combined to make a complete analysis not only one of great difficulty but one of danger to the specimen as well. The circlet of five contiguous and similar plates next the proximal stem joint is, however, clearly seen and the outlines of other plates of the injured area may be easily followed. A partial analysis of this syntype, showing five vertical rows of plates, is presented in text figure 25.

The other syntype is here designated as B and is illustrated by text figure 22. This specimen shows some thirty and more plates in



FIG. 22 *Palaeocystites dawsoni* Bill. Syntype B. x3
 FIG. 23 *Palaeocystites dawsoni* Bill. Apotype x3

the vicinity of the mouth and anus. Early efforts to clean the specimen seem to have removed some portions of the plate surfaces, but sutures and sutural canals are very clearly seen. Syntype B thus supplies a large and important area for analysis and the plate arrangement of this region is presented in figure 24. These two syntypes were both collected by E. Billings from the Chazy of the island of Montreal.

With some specimens also collected from the Chazy of the island of Montreal by E. Billings, but labeled *Palaeocystites tenuiradiatus* Hall, is a third specimen of *P. dawsoni* which is here made an apotype and is illustrated by figure 23. The specimen is only a fragment but it presents us with a complete cross section of the theca just below the anus. The ten vertical rows are here represented by a zigzag circle of plates, a higher and a lower regularly alternating with each other. Several plates show above this ring but the plates nearest the mouth seem to be lost. The epithelial canal coverings of this specimen have been removed by purely natural processes and in so delicate a manner that their extreme thinness is still manifest by their remaining edges. The character of both epithelial and sutural canals is revealed with excep-

tional clearness. The greatest width of this specimen must have been 13 mm.

Plate arrangement. The following description of the plate arrangement is based on the drawings here given and is further aided by an examination of the injured area of Syntype A and the cross section of the apotype.

The cirlet next the stem consists of five, similar pentagonal plates which strongly suggest the IBB of Crinoidea. Above these and alternating with them is another cirlet of five plates. These are septagonal and suggest the BB of Crinoidea. The two aborad shoulders of each of these plates rest against the orad shoulders of two plates of the first cirlet, while their vertical shoulders meet each other. There remain three shoulders which lie above their common vertical sutures and the uppermost of these is horizontal. Resting on each of these five horizontal shoulders is a vertical row of 3 or 4 hexagonal plates which for convenience we may for the present consider as interradial in position.

Five other vertical rows of three or four hexagonal plates alternate with the first rows mentioned and we may temporarily consider them as radial in position. Each vertical row of the second series is sup-

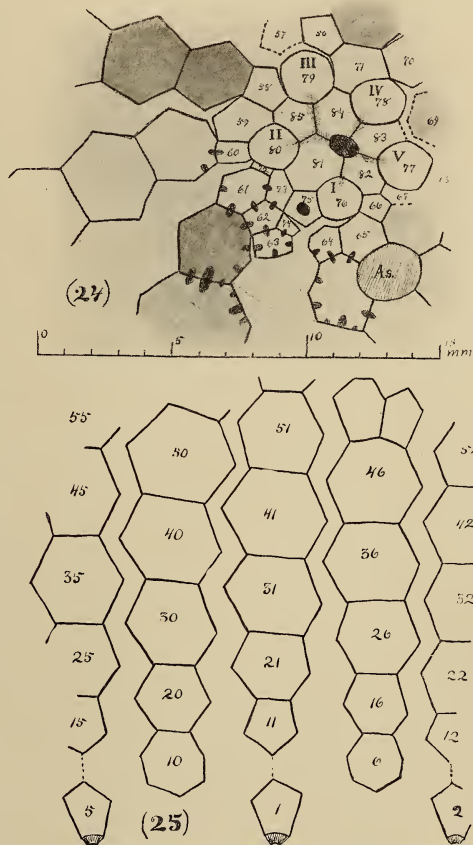


FIG. 24, 25 *Palaeocystites dawsoni* Billings. The former a partial analysis of syntype B. The more distant interradial plates of figure 24 are shaded and the position of the food grooves indicated.

It is to be understood that figure 25 shows but half or one side of the conical and cylindrical portions of the theca and that this lower figure is not intended to connect with the upper. The two areas mapped may fail to meet in some places and may overlap in others. The numbers given the plates are simply for convenience in reference. Numbers 55 and below belong to the figured plates of syntype A and the numbers above 55 refer solely to plates of syntype B.

ported on the horizontal shoulder of a separate pentagonal plate and these five pentagonals are very similar in form and position to the RR of the Rhodocrinidae.¹ The ten rows of hexagonal plates are capped by a circlet of ten plates, five of which have become septagonal and the whole circlet supports fifteen smaller plates. The regularity of the circlets of plates and the pentamerism of the aboral two-thirds of the theca are now both lost. A partial circlet of some three plates is introduced to the left of the anus and below a peculiar pentagonal plate which lies next to an oral and a basal arm plate. This pentagonal plate has a large central pore which probably represents either the hydropore or the genital opening. Passing oral we again meet with pentamerous symmetry in the form of five rather circular basal arm plates or radials, and five orals. The species thus has a theca composed of between 85 and 90 plates.

Food grooves and pentamerous symmetry. The arm over the anus and the two arms to the right of this each send a food groove directly into the mouth by means of a short and straight passage along the suture between two adjacent orals. The two remaining food grooves are bordered by three orals and these grooves meet each other before entering the mouth.

It will be noticed that the orals, while five in number, are neither symmetrical in form nor in radial arrangement. Pentamerous radial symmetry is thus somewhat imperfectly expressed by the food grooves, orals and basal arm plates. It is next wholly lost but is present in great perfection in six or more circlets nearest the proximal stem point. In other words, pentamerism has here apparently developed from two opposite poles and the aboral pole has attained the greater perfection and extended its influence to the greater distance. It is not the intention here to call in question the theory that pentamerous symmetry was due primarily to the bifurcation of the two food grooves extended to the right and left of the hydropore and anus in a primitive three-rayed form. We must not yet,

¹ In using a criñoid terminology in describing the aboral portion of the theca, there has been no intention of implying that the plates of the first circlet are really radial in position and lead to the unshaded plates or probable radials of figure 24. The form may be monobasic or tribasic. The true relation of these plates might, however, be determined by additional work on Syntype A. The borrowed terminology was used for convenience and to emphasize the very perfect pentamerous symmetry found in the aboral region of this species.

however, lose sight of such forms as possess what seems to be adverse testimony and particularly so when we must act not only as an advocate for both sides, but as judge as well.

It seems also proper to point out here that the tegmen of this cystid is very remarkably crinoidlike. A comparison of text figures 34 and 24 will make this manifest. The basal plates of the five arms show notches from which the food grooves ran over the edges of the five orals and passed into the mouth. These basal arm plates may well be considered as radials. The covering plates have been lost, but the grooves show plainly when the tegmen is viewed from the side. If the arrangement of the orals is primitive, it is also rather against the hypothesis that pentamerism arose through the forking of primitive right and left rays. It looks here as if a primitive anterior ray had forked to produce rays II and III.

Ornamentation. The ornamentation shown in text figure 21 may be said to be formed by an elaborate system of strongly raised, interlocking, hexagonal ridges. Each hexagon viewed separately is seen to contain a six-rayed figure whose strong ridges terminate at the angles of the hexagon. Each of the triangular pits so formed contains one smaller and less prominent triangle within it.

A study of text figure 23, and particularly of figures 26-33, will show that we are here dealing with an elaborate system of covered epithelial respiratory canals very similar to those already seen in *Palaeocrinus striatus* and it will be well to compare them with those of that species. Each suture between the larger plates has but three sutural canals. The diameter of the largest, as shown deep in the basin between plates 1 and 2 in figure 29, appears to be but 0.2 mm wide. The distance apart on a suture is from 0.6 to 0.7 mm or a distance slightly greater than in *P. striatus*. These sutural canals open into basins which are not short as in *P. striatus* but which extend to the ends of the epithelial canals and become shallower with marked regularity. These basins are also widened upward on the suture until they attain a diameter about twice as great as the canal leading into them. The long canal-like character shown by these epithelial structures in *Palaeocrinus striatus* is completely masked. Epithelial basins would here be the more appropriate term. When these basins are covered, the ridges of the larger are 0.45 mm wide and appear apparently flat topped. At least they appear so in the cleaned surface of one of Syntype A as shown under a gum dammar mounting and reproduced in figure 32. The oval basin of this species is partly shown in this

figure through a semitransparent covering, if we closely examine the large canal leading from plate 31 to 26. In figure 27, from Syntype

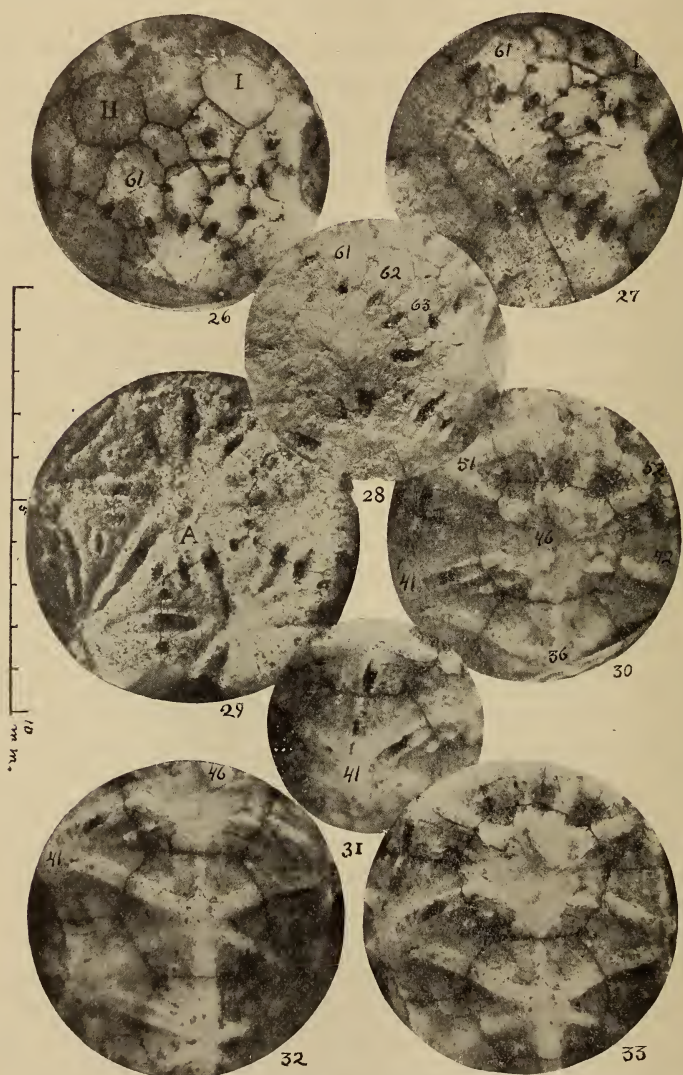


FIG. 26-33 *Palaeocystites dawsoni* Billings. Figures 26 and 27 are from photomicrographs made of Syntype B under a gum dammar mounting. Figure 28 shows the area of 27 as photographed without the mounting. Figure 29 is of the apotype, without mounting. Figure 30-33 are from photomicrographs of Syntype A, all with the dammar mounting but from different negatives. For plate numbers see fig. 24 and 25

B the dammar mounting has left the basins too dark and the sutural canals can not be seen. The same area without the dammar is shown in figure 28 and the difference in results of the two photo-

graphic processes should be given careful study. The features of the basins are, however, not essentially different from those shown in figure 29 which is of the apotype and photographed without mounting. The diameter, distance apart, number on the suture and the shape of the basins should enable one to easily determine this species whether intact, weathered or crumbled into separate plates.

Figures 30-33 show also a detail of very considerable interest. The figures are from four different negatives and thus show the feature in different lights. Plate 41 of these figures had at one time a sutural canal near the middle of the suture between it and plate 42. Plate 41 seems to have extended this sutural margin a little more rapidly than its neighbor or else it failed to

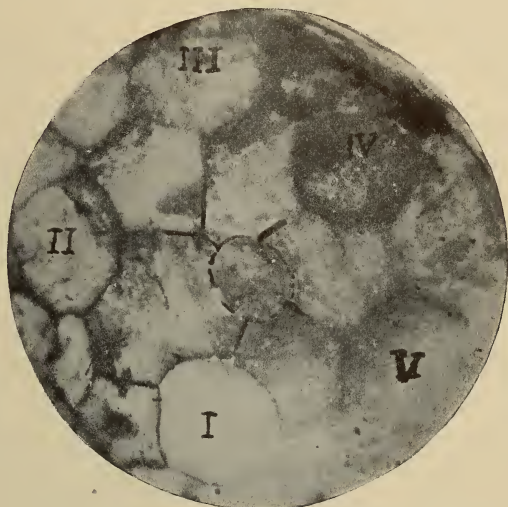


FIG. 34. Photomicrograph of tegmen of *Palaeocystites dawsoni* Billings. $\times 10$. Compare with figure 24

place stereom back of the canal. The result was that this plate had soon surrounded the canal and left the suture without one at this point. It was pointed out on page 199 that such a thing might occur, and in plate 6, figure 3, at *c* (see also figure 4 of the same plate), we saw a canal nearly so inclosed. This then is a case in which such inclosure did become complete and a perforated plate is the result.

In figure 26 at *m* we have also a perforated plate, but this is no doubt a normal feature and represents either a hydropore or genital pore. The size of the anus as compared with the mouth is an indication of anal respiration.

Sigmacystis emmonsi Hudson

Malocystites emmonsi Hudson. Report of the State Paleontologist for 1903. N. Y. State Mus. Bul. 80, p. 270.

The species cited above is congeneric with *Malocystites barrandi* Billings but both differ so much from *Malocystites*

murchisoni Billings as to entitle them to generic distinction. The following genus is therefore proposed.

SIGMACYSTIS nov.

Cystidea with two short, main food grooves. The anterior curves strongly to the right and the posterior strongly to the left forming



FIG. 35 *Sigmacystis emmonsi* Hudson. From a photomicrograph of specimen C now in the State collection at Albany. The probable appearance of seven of the ten arms is indicated. Several articular facets may be clearly seen.

together a letter S with the mouth in the center. These food grooves follow a line of sutures, but do not cross sutures unless at the extreme ends. The concave side of each is formed by the raised edge of two orals, while the convex side is formed by the inner

edges of a short series of basal brachiolar plates or armlet ossicles. These plates have wedge-shaped insertions and reach nearly or quite through to the inner surface of the theca. The brachioles or armlets next to the mouth are large and long and may have been compound. As their distance from the mouth increases, their diameter and length rapidly decrease (see text fig. 35). The plates of the theca are reduced on the anterior side to nearly or quite three partial circlets. The posterior area is much inflated and requires some five to seven or more plates to reach from the stem to the orals. Stem narrow, short and weak and not able to support theca.

Differs from *Malocystites* Billings in that its armlet or brachiole-bearing plates do not run over the surfaces of other thecal plates and across their sutures but are, on the contrary, raised into a higher food-collecting territory and are capable of considerable adjustment (a modification necessitated by loss of supporting stem). The sigma, with its short arms and the rapidly changing size of its basal armlet ossicles, is in itself a sufficient distinguishing character. In *Sigmacystis* anterior plate reduction has progressed farther than in *Malocystites* and the mouth has thus been drawn farther over toward the proximal stem joint.

The specimen described as *Malocystites emmonsii* in the Report of the State Paleontologist for 1903, there designated as "specimen C" and figured on page 276 and again in plate 1, figure 7, is now made the holo-genotype of *Sigmacystis*. The necessity for a new generic name for these forms was also recognized independently by Dr Percy E. Raymond. While my name was in manuscript he kindly loaned me his entire pelmatozoan collections from the Chazy beds and I find there these forms given the practically identical name of *Sigmacystites*. *Malocystites murchisoni* Billings remains the genotype for *Malocystites*.

In Canadian Organic Remains, Dec. III, p. 66, Mr Billings calls attention to the absence of evident pores in the plates of these genera and compares his *Malocystites* with *Cryptocrinus* von Buch. Through the courtesy of Doctor Whiteaves I was loaned a box containing two cystids collected by Mr Billings and labeled "*Cryptocrinus*, Chazy, near St Michel, E. B. 1857." One of these is a well-preserved specimen of *Sigmacystis emmonsii* and its plate analysis is given in text figure 36. This species is presented here in advance of a more detailed study of the group for the purpose of lending emphasis to the point made with reference to the origin of pentamerous symmetry.

The Plattsburg, N. Y., specimens of *S. emmonsii* whose analyses were published in the report already cited, had but three plates

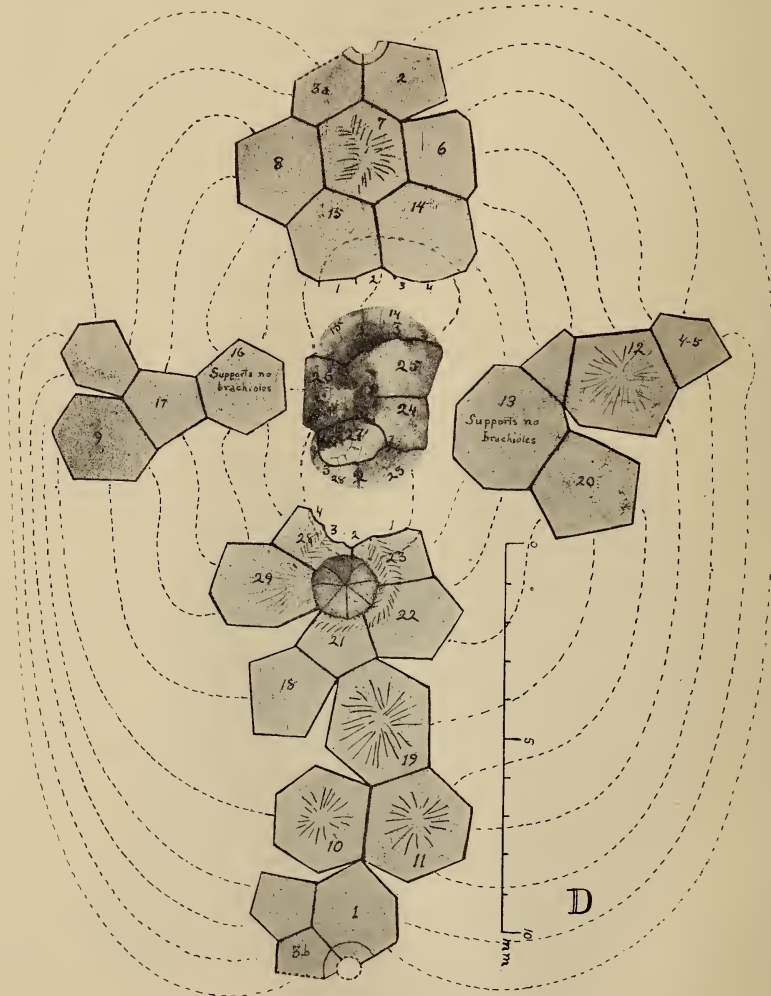


FIG. 36. Analysis of *Sigmacystis emmonsii* Hudson, specimen D. The specimen found by E. Billings near St Michel in 1857. The plates are numbered to correspond with the analyses already published and the more prominent mounds and ridges are indicated by hachures. The four oral plates and portions of plates 14, 15, 23 and 28 are from a photomicrograph and are used to illustrate the character of the sigma. The pits occupied by the proximal brachliolar ossicles have had their approximate outlines dotted. There seems to have been but four of the latter bordering each main food groove. The genital pore and madreporite are indicated by hachures. The anal covering plates are also from a photomicrograph. All sutural lines on the photographic portions of figure have been intensified.

in their first (aboral) circlet. Two of these, however, appear to be double plates, the 1.ant.IR alone remaining single. In the St Michel specimen the 1.post.IR and the post.IR seem to have been

separate plates in the nepionic stage, for the plate numbered 3 in the analysis shows a central trace of a suture and is clearly and definitely notched exactly above it to admit the aboral angle of the plate above 9 and 17 in figure 35. With these plates separate, the arrangement of the circlet would be as in the Glyptocystidae where the r.post.IR is always fused with the r.ant.IR of the same circlet. These analyses all suggest an original circlet of five plates next to the proximal stem joint, but the oral region shows neither trace of an original pentamerous symmetry nor of a still earlier triradial extension of food grooves which would lead to a subsequent five-rayed form through the forking of the right and left posterior rays of the original three. It must be kept in mind, however, that *Sigmacystis* is a specialized form. This is shown by the reduction in the number of its plates, loss of primitive stem function and change of position of mouth to side of theca.

Sigmacystis does not possess a system of epithelial respiratory canals and shows no trace of either pore-rhombs or pectinirhombs. The large anal opening and inflated anal area suggest a more or less elaborate system of anal respiration. *Schizocystis* Jaekel (1895) and other members of the Glyptocystidae point the road to a total loss of pectinirhombs and to plates with a raised central mound and nodular surface, as in *Sigmacystis*. The affinities of this genus will be discussed in a future paper.

I have been under many obligations to the late Dr J. F. Whiteaves, to Dr John M. Clarke and Dr Percy E. Raymond for generous loans of material and other help and to Dr Rudolf Ruedemann, Mr Edwin Kirk and Jacob Van Deloo for assistance in procuring literature.

NOTE. Additional evidence for my conclusion that the b.vs. surrounding a plate corner "are but external branches of one internal tube or chamber" (see page 225, lines 10, 11) are to be found in a recent and very valuable paper by Mr Frank Springer "On a Trenton Echinoderm Fauna at Kirkfield, Ontario" [Canada Department of Mines, Memoir No. 15-P] which was received while my present paper was in press. I refer to p. 43, lines 12 to 16 inclusive and plate V, figures 10e, 11b and 11c. These figures show definitely the branching of the inner portion of a corner b.v. not below the theca but within the walls of the suture itself. These

branches each branched again on reaching the surface of the plates and lay at right angles to the suture in epithecal canals developed with them. The comparison of my *Cliocrinus perforatus* with the new *Cliocrinus sculptus* of Springer will show how readily a species having only sutural canals could develop a species with corner canals closed but with "rhombs" on the sutures.

EXPLANATIONS OF PLATES

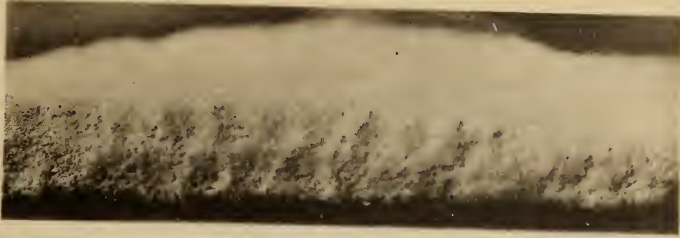
Plate I

259

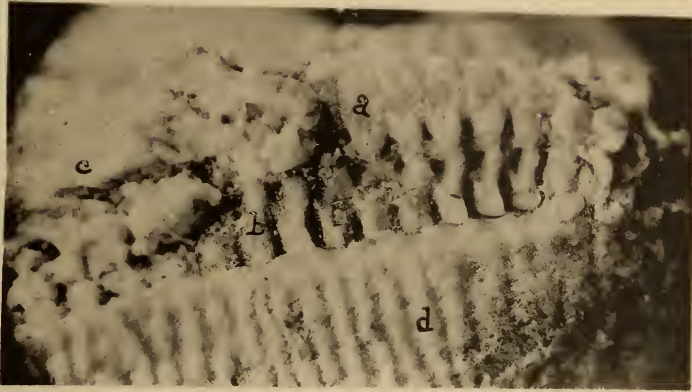
Blastoidocrinus carcharidens Billings

FIG. 1 Photomicrograph $\times 10$ of a portion of the underside of a wing plate. A small figure of this specimen was given in Bulletin 107, plate 6 at *k*. The oral end is at the right. The undersurface shows that it was in close contact with the covering plates. In the collection of the State Museum

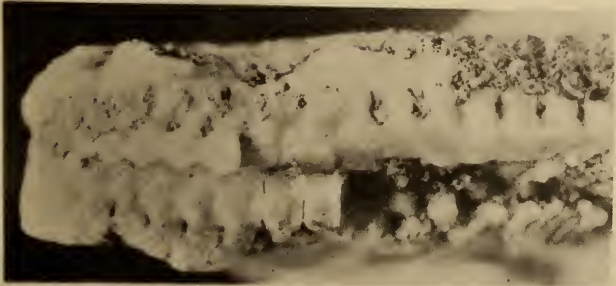
- 2 Photomicrograph $\times 10$ (through error the enlargement here was very slightly under 10 dia., the correct ratio being $58=6$) of a small area of the fragment figured in Bulletin 107, plate 5 at *j*. The oral end is at the left.
 - a One of the ossicles covering the left side of a food groove. Its boundaries have lost some of their distinctness through the process of reproduction from the photograph but are still recognizable. Back of this left row the tops of several members of the right row are shown. The groove between them carried a wing plate like that shown above.
 - b The outer face of one of the adambulacrals. The vertical oval-shaped openings are portions of food-collecting basins that discharged their food through smaller pores opening directly into the food groove. The narrower dark vertical channels leading down from the food-segrating basins were drainage channels for surplus water and discharged into the hydrospires. Views of these channels as seen from above are shown in the three remaining figures from uncovered adambulacra.
 - c Remains of portions of the brachioles which still remain attached to both adambulacra and covering pieces.
 - d The upper edge of a deltoid. This fragment is from Valcour island, Lake Champlain, and belongs to the Carnegie Museum.
- 3-5 Photomicrographs $\times 10$ of upper surface of portions of the three adambulacra still present in the type specimen. Six covering pieces still remain on the "arm" shown in figure 3, but these are much weathered. The remaining figures show only the upper surface of the adambulacra, the traces of the food groove, the openings into the hydrospires and the edges of the deltoids. In the Museum of the Geological Survey of Canada



1



2



3



4



5

Plate II

261

Blastoidocrinus carcharidens Billings

- Fig. 1 Photomicrograph of a portion of the type x10. This is a side view of the portion of an ambulacrum shown in plate 1, fig. 3
- 2 Photomicrograph of a portion of the inner surface of the deltoid figured in Bulletin 107, plate 5 at *n*

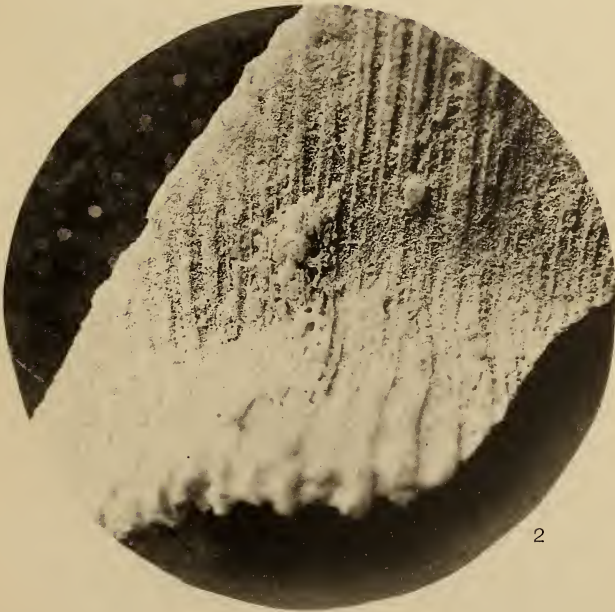


Plate III

263

Blastoidocrinus carcharidens Billings

Fig. 1-2 Photomicrographs of nearly the same area of the type
but from different aspects x10

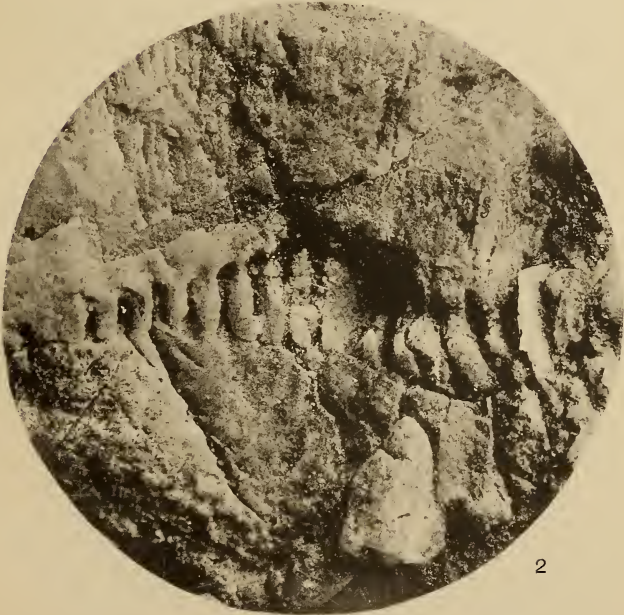
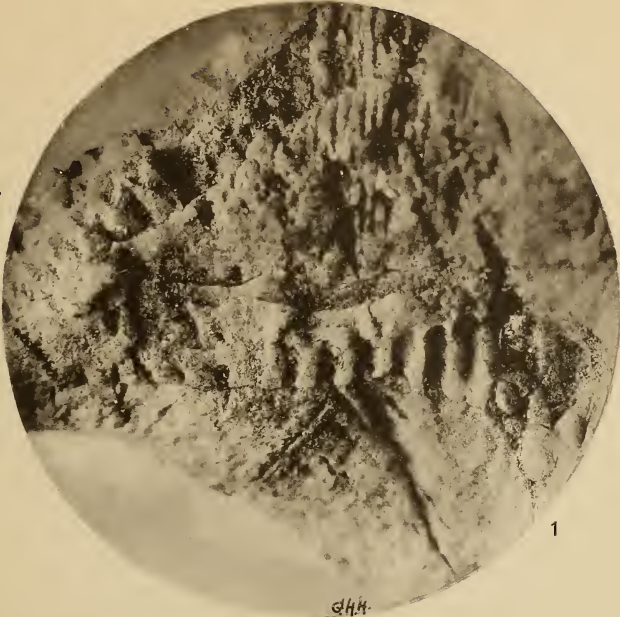


Plate IV

265

Blastoidocrinus carcharidens Billings

Fig. 1 Reproduced from photomicrograph of the weathered face of the type and showing the position of the stem which Billings took to be a natural one. $\times 3$.

Shows also the outer edges of three displaced columnals at lower right of stem. These were uncovered by the removal of some of the foreign material lodged in the basin formed by the infolded radials.

2 The proximal portion of the stem shown above as revealed by a photomicrograph taken through a gum dammar mounting. The broken edges of the basals are clearly revealed and the beginning of the narrow stem lumen shown. The displacement of the columnals due to probable intrust at death (the form being covered and preserved from passage through the alimentary canal of some larger form with consequent plate separation) is clearly manifest.

3 A detail of the hydrospires shown just to the right of the proximal end of the stem in fig 1, $\times 10$. The rounded inner edges of the water-bearing cavities of the hydrospires have been weathered away in the upper portion of the figure but still show just below the broken edges of the sheetlike sides of these cavities.

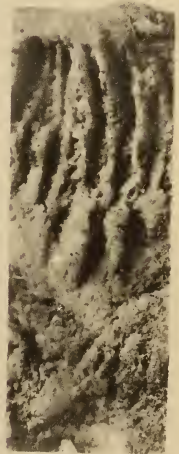
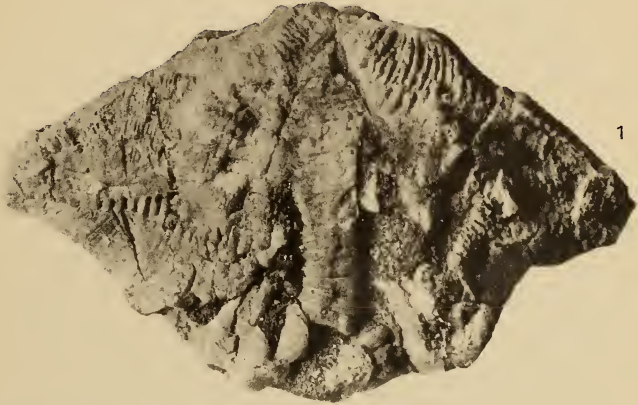


Plate V

267

Palaeocrinus striatus Billings

- Fig. 1 Ten diameter enlargement of area over l.ant.IB
- 2 Same area as photographed under a mounting of gum dammar
- 3 Ten diameter enlargement of area around upper angle of r.post.B. The probable path of the right-hand branch of the oldest b.v. is indicated by four dots on r.ant.R
- 4 Same area as it appears under a mounting of gum dammar. The curved bands of light and shade which appear near the corners of the two lower figures are due to refraction and reflection from the edges of the drying gum

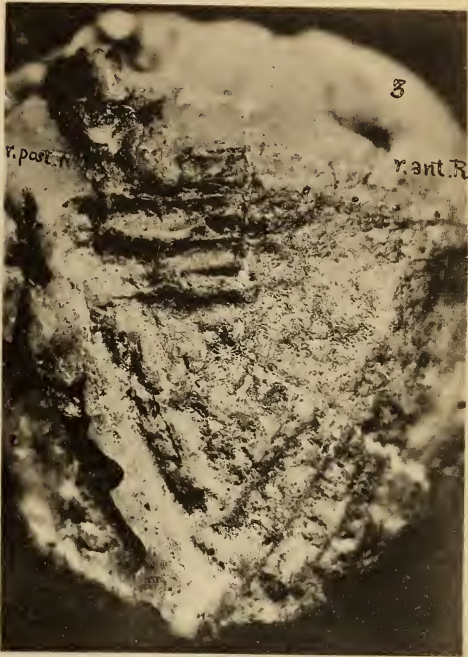


Plate VI

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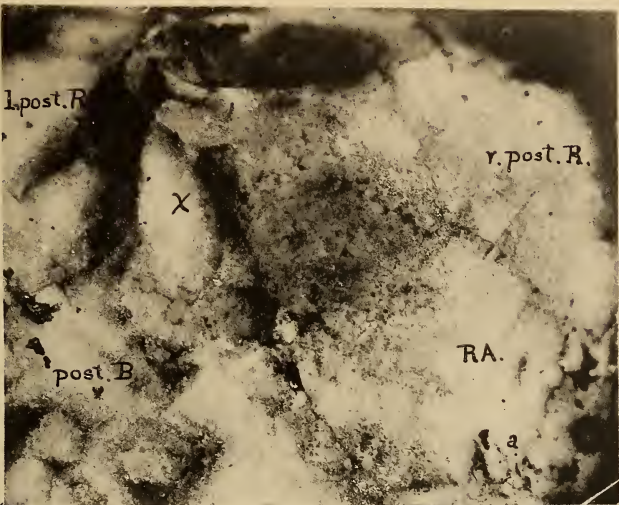
Palaeocrinus striatus Billings

The figures are from photomicrographs of the holotype x10 and taken under a mounting of gum dammar. They are here reproduced without retouching. Each figure is from a separate negative. Figures 1 and 2 show this surface as it was when Mr Billings made his description.

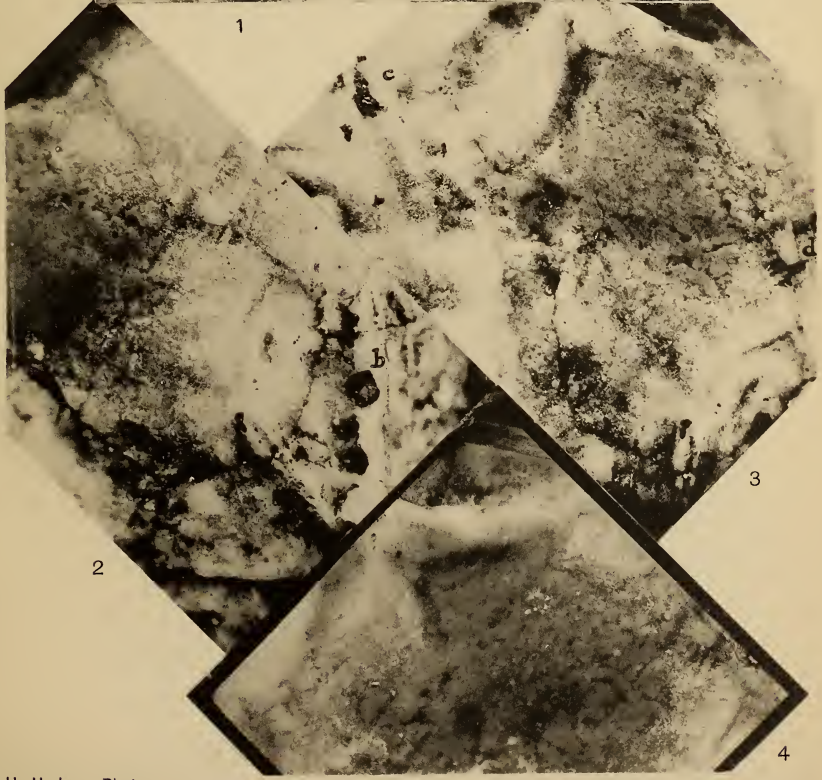
Fig. 1-2 Radial and adjacent plates. That the radial is four sided instead of six, as heretofore figured, may be here clearly seen. The approach to an angle on the lower right margin (next r.post.B) is due to the bowing out of the plate and the angle from which this curved surface is seen. The effect is very like that of a meridian on a globe photographed at an angle. The cross sections of carbon lined sutural canals on upper margins of post.B are fairly well shown.

- 3 A view of this region after the removal of a layer about 0.1 mm thick from a small area of the X and RA
- 4 A view of the same area after the removal of an additional thin layer. The thickness of the last layer removed was from 0 mm at the right to between 0.1 and 0.2 mm at the left. The area of subtheical tubes is seen to be more extended at the left. A yellow color screen was used for this negative

Figures 3 and 4 do not reveal the finer detail of sections of supposed diverticula from the rectum which is shown in the photomicrographs. If it be remembered that in these figures the area around the suture between RA has been cut down with a file and that such features as show are subtheical the figures may still show features of interest.



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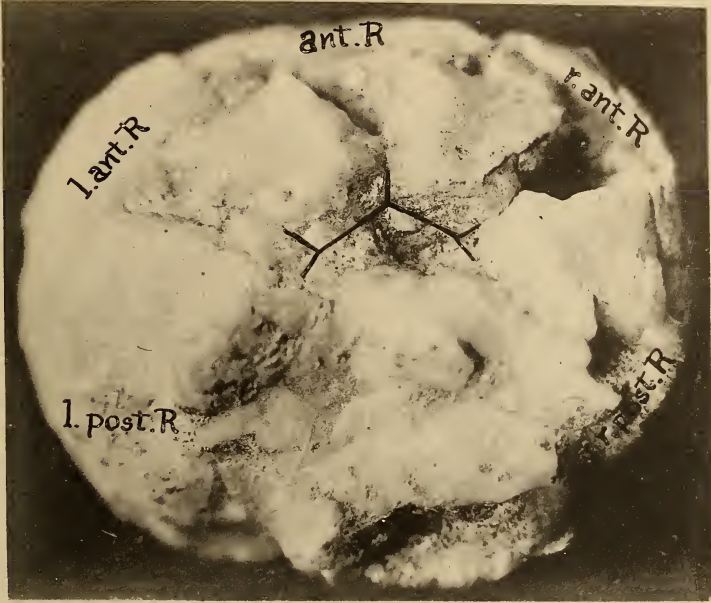
4

Plate VII

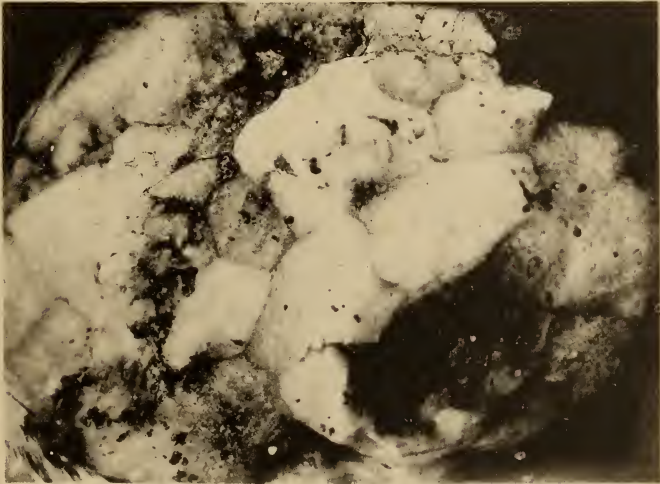
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Palaeocrinus striatus Billings

- Fig. 1 View of oral region from photomicrograph x10. The area was not covered by the gum dammar mounting
- 2 View of the anal area from photomicrograph x10. The area was covered with gum dammar solution and a cover glass. The madreporite and the ambulacrals and adambulacrals of the food groove above and to the right of it are all clearly seen



1



2

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Appendix 1

Geology

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- 146 Geologic Features and Problems of the New York City (Cats-kill) Aqueduct

Education Department Bulletin

Published fortnightly by the University of the State of New York

Entered as second-class matter June 24, 1903, at the Post Office, at Albany, N. Y.,
under the act of July 16, 1894

No. 485

ALBANY, N. Y.

DECEMBER 15, 1910

New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 145

GEOLOGY OF THE THOUSAND ISLANDS REGION

ALEXANDRIA BAY, CAPE VINCENT, CLAYTON, GRINDSTONE AND THERESA QUADRANGLES

BY

H. P. CUSHING, H. L. FAIRCHILD, R. RUEDEMANN AND
C. H. SMYTH JR

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*New York State Education Department
Science Division, October 4, 1909*

Hon. Andrew S. Draper LL.D.

Commissioner of Education

SIR: I have the honor to communicate herewith for publication as a bulletin of the State Museum a manuscript entitled *Geology of the Thousand Islands Region*, covering the areas known as the Alexandria Bay, Cape Vincent, Clayton, Grindstone and Theresa quadrangles. This is a report upon several seasons of field work in the region referred to, by Prof. H. P. Cushing, Prof. Herman L. Fairchild, Dr Rudolf Ruedemann and Prof. C. H. Smyth jr of this staff.

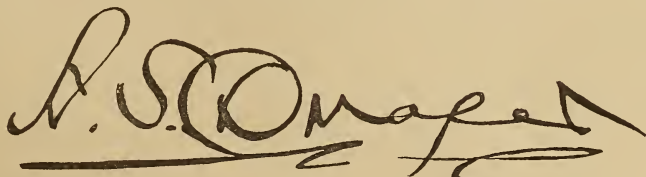
Very respectfully,

JOHN M. CLARKE

Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 5th day of October 1909



A. S. Draper

Commissioner of Education

Education Department Bulletin

Published fortnightly by the University of the State of New York

Entered as second-class matter June 24, 1908, at the Post Office at Albany, N. Y., under the act of Congress of July 16, 1894

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BY

H. P. CUSHING, H. L. FAIRCHILD, R. RUEDEMANN &
C. H. SMYTH JR

INTRODUCTION¹

The field work on which the accompanying report is based was done during the field seasons of 1906, 1907 and 1908. The district was chosen for work chiefly on the recommendation of Professor Smyth, and work was begun by the writer with the understanding that we were to collaborate in doing it. Unfortunately this plan failed of realization, owing to Mr Smyth's inability to take the field, so that his actual participation in the work was limited to a portion of the season of 1908, during which he mapped the major portion of Wellesley island.

Dr Ruedemann assisted in the mapping of the southern part of the Theresa quadrangle during two weeks of the season of 1907 and in 1908, mapped Cape Vincent and the southern half of Clayton. The remainder of the areal mapping is the writer's contribution, comprising the Theresa, Alexandria and Grindstone sheets (with the exception of Wellesley island) and the north half of Clayton.

NOTE. The photographs credited to Ami and Ulrich are published by permission of the Directors of the Geological Surveys of Canada and of the United States.

¹ By H. P. Cushing.

Professor Fairchild spent the season of 1908 and portions of two previous seasons in the study of the Pleistocene geology of the area, and his reports will be found included in their appropriate places.

During both the seasons of 1907 and 1908 Dr E. O. Ulrich of the United States Geological Survey was in the field for a time with Dr Ruedemann and myself. In 1908 Dr H. M. Ami of the Geological Survey of Canada was also present and we spent 10 days together, chiefly in study of the Pamela, Lowville and Black River limestones, with a short excursion to the district around Kingston, under Dr Ami's guidance. Combined work of this sort is of the utmost value, and as a result of it the indirect contribution of both these gentlemen to this report is most important and is gratefully acknowledged.

In a previous year Professor Smyth had reported upon the larger part of the district comprised in the Alexandria and Grindstone sheets, as well as their eastward extension, doing the work as accurately as the imperfect base map at his disposal warranted. It is a pleasure to testify to the importance and accuracy of this report, especially in view of the date at which, and the circumstances under which the work was done.¹ The different rock groups and their relations to one another were thoroughly worked out, and the independent mapping here reported upon has done little more than to repeat his work and emphasize its correctness. This of itself would justify his appearance as a collaborator in this report, independently of his direct contribution.

For five weeks of the season of 1908 Dr H. N. Eaton of Chapel Hill, N. C., served as voluntary assistant. This generously given help is gladly acknowledged, and the report also bears witness to the service of his camera.

LOCATION AND CHARACTER ²

These five quadrangles constitute the extreme northwestern portion of northern New York, bordering the lower end of Lake Ontario and the St Lawrence river in the Thousand Islands region. The area mapped extends from the meridian of 75° 45' w. longitude to Lake Ontario and from latitude 44° to the national boundary. It comprises some 560 square miles.

¹Geology of the Crystalline Rocks near the St Lawrence River. N. Y. State Geol. 19th An. Rep't 1899. p.185-104.

²By H. P. Cushing.

The area is one of low altitude and comparatively little relief, forming the west end of the plain which borders the entire north front of the Adirondack highland, and merges hereabouts into the north end of the Black river lowland. To the southward the altitude considerably increases and a bit of the high Trenton escarpment which forms the west wall of the larger part of the valley of the Black river, appears in the extreme southwest corner of the Theresa sheet, reaching an altitude of over 800 feet, the highest elevation in the mapped district. Altitudes considerably in excess of this appear not far to the southward on the Watertown sheet. But with this one trifling exception the highest elevations in the mapped area but little exceed 600 feet (this in the southeast corner of the Theresa sheet) and thence drop gently to the north and west to the level of the lake and river (246 feet).

Though the district is thus moderately flat, the local relief is considerable, in minor fashion. Ridges and valleys characterize the districts underlaid by Precambrian rocks. The flat-lying Paleozoic rocks form plains which are fronted by steep cliff-escarpments. In both cases abrupt changes of level of from 50 to 100 feet are quite common. These features also are most pronounced in the eastern part of the area and fade out westward, so that but little relief is manifested on the Cape Vincent and the larger part of the Clayton sheet.

With the exception of the St Lawrence, the Black and Indian rivers are the only streams of respectable size within the mapped area. Most of the streams flow in narrow, steep walled valleys, and no deep, broadly opened valleys have been detected. There are many features of interest in the minor drainage to which attention will be directed later on. The group of lakes of an unusual type forms a very prominent feature. Several of these lakes may be noted near the eastern edge of the Alexandria sheet and there are a few more beyond the map limits. They are not a usual feature of this part of the State. Their presence and their very localized distribution require explanation.

Glacial deposits are in small bulk in the district and much bare rock appears, with wide areas where the soil is very thin. In the limestone districts the streams show a tendency to go underground and bared limestone surfaces show considerable amount of rock removal through solution along the joint planes.

The district is largely one of small farms. Little or no forest remains on it, though there is much waste land. The largest

single area of the sort appears in the southeast part of the Theresa sheet, on which is found the western portion of the "sand plains," the great Pleistocene delta of the Black river.

Interesting historically from having been the scene of exploitation and settlement by French immigrants of high class, during the early part of the nineteenth century, the district preserves many traces of this immigration, especially in the matter of geographic nomenclature.

SUMMARY OF GEOLOGIC HISTORY¹

The rocks of the region are readily separable into two great groups, the one of older crystalline rocks, and the other of younger sandstones, limestones and shales which rest upon the older group. The rocks of the older group are of Precambrian age, are among the most ancient rocks of which we anywhere have knowledge, and are in most respects identical with the crystalline rocks which compose the great central region of northern New York, the Adirondack region, and with those of the much more extensive area which lies to the northward in Canada. These rocks, in the district here reported upon, form a narrow connecting link, or isthmus, between the exposures of these two areas, which otherwise are completely separated from one another by a belt of country of considerable width in which the surface rocks belong to the younger group. It is only in the immediate region therefore that direct connection can be traced between the old rocks of Canada and of New York, and this fact gives added interest to the study of these rocks here.

These Precambrian rocks furnish us with our most ancient direct records of the history of the earth, but like most ancient records they are fragmentary and difficult to decipher. Nevertheless they plainly indicate that Precambrian time was of enormous duration, involving many millions of years.

Here, as elsewhere in northern New York, these rocks consist of but a single series of water-deposited rocks, so far as our knowledge goes. This is known as the Grenville series, and comprises rocks which, originally deposited as shales, limestones, and sandstones, are now greatly changed in character and have become white, coarsely crystalline limestones, glassy quartzites, and schists and gneisses of many varieties. Curiously we have not as yet, in

¹By H. P. Cushing. This is a simple statement of the outlines of the history of the region as disclosed by the study of the district. The detailed evidence upon which these statements are based, will follow later.

New York, been able to discover anywhere any trace of the older rocks which formed the floor upon which these water-laid sediments were deposited, though plainly, with such an origin, they must originally have been laid down on some such floor of older rocks. It follows therefore that we do not know the base of this Grenville series. Neither do we know its summit, since that has apparently been everywhere removed by erosion. Hence we can not know its thickness, though we do know that it is a very thick rock series, several thousands of feet at least.

Since the deposition of this formation it has undergone many changes. The rocks have been greatly compressed and intricately folded and plicated. They have been invaded from beneath by huge masses of igneous rocks, which have broken up the once continuous Grenville formation into separate and disconnected belts and patches, have probably engulfed and digested large amounts of it, and are likely responsible for the utter disappearance of the old floor on which the formation originally rested. As a result of this mishandling the rocks have been profoundly changed in character. They have been entirely recrystallized, with complete destruction of the textures which, as sediments, they originally possessed, and with the production of a foliation cleavage, or schistosity, due to a banded arrangement of the minerals formed by the recrystallization. In addition a quantity of contact rocks has been produced in the vicinity of, and by the action of, the igneous rocks, which interact with the others to produce rocks quite different from either, and with opportunities for manifold variation, with variation in the character of either or both sets of the original rocks. In this manner many rock types have arisen, often of puzzling nature.

The changes which have been produced in these Grenville rocks are of such nature as to lead to the confident belief that they took place at some considerable depth below the surface, or in other words that a considerable thickness of other rocks then overlay them, a rock thickness which subsequently disappeared because of surface wear continued through long ages.

Igneous intrusions

As has been implied the Grenville sediments are the most ancient rocks of which we have definite knowledge in northern New York. Subsequent to their formation they were repeatedly invaded from beneath by igneous rocks in molten condition. In the immediate district the bulk of this igneous rock consisted of granite, and

the more basic rocks which appear in large quantity further east are but sparingly present. But granitic intrusion took place on a large scale at least twice, probably three times, and possibly several times. This it was which was so effective in breaking up, altering and destroying wholesale the Grenville sediments and their floor.

Laurentian granite gneiss. The oldest of these igneous rocks is a granite which has, since its intrusion, been sufficiently subjected to compression to have become pretty thoroughly crushed, or granulated, with the development of a rude foliated, or gneissoid, structure. It is a reddish to gray granite gneiss which contains nearly everywhere inclusions of the Grenville rocks in varying abundance, but always most abundant near the contacts with the Grenville, into which it always sends a multitude of dikes. The inclusions are usually of amphibolite and all stages of their assimilation by the granite are found, giving rise to a group of intermediate rocks which seem unquestionably to have been derived from the digestion of the one rock by the other. It is possible that some of these amphibolite inclusions may actually represent fragments of the old Grenville floor, and furnish the sole remaining traces of that floor, but as yet this is mere conjecture. This granite gneiss occurs in both large and small masses, so called bathyliths and stocks, which invaded the Grenville rocks from beneath at an exceedingly early period.¹ In addition to forming a large portion of the present surface occupied by the Precambrian rocks it likely also underlies the Grenville rocks over the entire district, except where they have been cut away by succeeding igneous rocks. Since the rock solidified it has been subjected to compression, together with the Grenville rocks, giving to each a foliation parallel to that of the other, and elongating the bathyliths in a northeast-southwest direction with corresponding shortening at right angles to this, the shortening being of course in the direction of the pressure and the elongation at right angles to it.

Alexandria syenite. On the Alexandria quadrangle, some 3 miles a little west of north of Redwood, is a mass of rather coarse grained igneous rock which shows little sign of crushing and is unquestionably younger than the Laurentian granite gneiss. In association with it is a much greater amount of a coarse, but crushed, porphyritic igneous rock, now converted into an "augen" gneiss.

¹ Bathylith is a term applied to large masses of igneous rock, which masses are believed to continue to great depths with generally increasing size downward. A stock is a smaller mass of the sort.

What relation the two bear to one another could not be definitely ascertained. Either the augen gneiss is a crushed border phase of the other, that representing an uncrushed core, or else it is a separate and older rock. It is a fairly basic rock, varying much in this respect, seems at times to owe its character to partial assimilation of amphibolite, and so far as seen, its exposed contacts are all with Grenville rocks, which it cuts. If the two intrusives belong together the mass reaches considerable size and is to be classed as a small bathylith. If the augen gneiss is distinct from the other the latter is only a stock.

In case the augen gneiss is distinct the question naturally arises whether it may not be merely a porphyritic phase of the Laurentian granite gneiss. A decisive answer to this question can not be given owing to lack of contacts between the two classes of rock. But such evidence as there is seems decidedly against such a correlation. The rock is a more basic one than the general run of the granite gneiss, and is not so severely crushed, or granulated. The weight of the evidence is decidedly in favor of the view that it is a gneissoid, border phase of the syenite.

Syenite southwest of Theresa. Up the creek valley above Theresa are exposures aggregating about a square mile in extent of a gray to gray green rock which is a syenite. It may have considerably greater extent underneath the sandstone which adjoins it on each side. It is by no means so mashed as the granite gneiss and seems clearly a younger rock, but since it is not found in association with any of the other younger igneous rocks its age relations to them are not ascertainable.

There is a single outcrop of a coarse, unmashed eruptive which is to be classed as a gabbro, close to the upper bridge at Theresa on the west bank of the river. It may have considerable extent under the adjacent sandstone but with the most generous possible allowance for such extension the mass would still have to be rated as a stock of no great size.

Picton granite.¹ The most extensive and important of these younger Precambrian intrusives is the coarse red granite which outcrops widely on Grindstone, Wellesley and some of the smaller

¹The most considerable outcrops of this rock within the State are on Grindstone island, but the name of Grindstone granite would perhaps be misleading, and Grindstone Island granite is too long a name. The smaller Picton island is however the seat of the chief quarries at the present time and the name would be wholly appropriate except for the fact that the island appears on the maps as Robbins island. It is universally called Picton island by residents, many of whom have no knowledge of any such name as Robbins island.

islands, and to a small extent on the mainland, and which is named from Picton (Robbins) island; where the most extensive quarries occur. This rock shows little or no signs of the crushing which has affected the other Precambrian intrusives in greater or less degree, though it becomes fine grained in certain situations, chiefly marginal, and notably so in many of the dikes which it sends out into the adjoining rocks.

The rock holds a multitude of inclusions, of Grenville quartzites and schists, of Laurentian granite gneiss, and of the augen gneiss associated with the Alexandria syenite. Over much of Wellesley island the abundant inclusions are but little disturbed. In other words their dips and strikes are concordant and in accord with those of the neighboring Grenville rocks, and with these unchanged dips and strikes the inclusions occur in linear belts, now of quartzite, now of schists and again of granite gneiss, so that the original distribution of these rocks can be mapped as confidently as though the granite invasion had never been. This indicates that here we are near the very roof of the granite batholith, where cooling had rendered it so stiff and pasty as to be no longer able to pluck away and engulf blocks from its roof, the present inclusions being such as had been last broken away but were unable to founder and retained their original orientation.

The utter lack of signs of crushing in the rock leads to the rather confident belief that it is the youngest of all these early Precambrian intrusives, though there is some question as to whether it is actually younger than the syenite and the gabbro about Theresa, and with no possibility of definitely settling the matter.

The batholith is also of large size, extending out of New York into Canada among the islands and on the mainland. The granite which outcrops about Kingston seems surely identical, and is distant 17 miles from the nearest outcrops of the rock on the west end of Grindstone island.

The molten mass of the granite was also richly charged with mineralizing fluids and hence exhibits prominent contact effects on the adjacent rocks, much more prominent than those shown by any of the other intrusives of the immediate region.

When compared with the Precambrian rocks of the general Adirondack region (the rocks hereabouts comprising the extreme western edge of the Precambrian of northern New York) the most obvious difference to be noted is the comparative scarcity of igneous rocks belonging to the syenites and gabbros in this western area.

It seems also to be the case that metamorphism is not so extreme

here as farther east, in fact there seems to be a slow but progressive increase in severity of metamorphism in passing east. The differences in this respect are not so prominent in the Grenville and Laurentian rocks as in the later igneous rocks, but characterize all. Even here, however, the character of the metamorphism indicates a considerable depth for the rocks concerned during the time when it took place. But it also suggests a less depth of overlying material than is possessed by the region farther east.

This overlying material has since been removed by slow surface erosion. Greater thickness has been removed on the east than on the west apparently, the differences in metamorphism being thus most readily explained. Further, this removal by erosion took place wholly in Precambrian time indicating that the region was a land area for a long period. Precambrian time however was very long, the Grenville sediments were deposited early in it, the district subsequently rose above sea level and remained as land during the long ages of the middle and late Precambrian. The large amount of rock thickness removed not only argues for a long erosion interval but likely indicates renewal of uplift on one or more occasions, since it is not probable that the region ever attained an altitude as great as that represented by the thickness of rock removed.

Late in Precambrian time, and toward the close of this long, erosion period, came renewed igneous activity, an upward movement of heavy, black, basic lava taking place. Not improbably some of this material reached the land surface of the time and spread out as lava flows. If so subsequent wear has removed every trace of their presence, cutting away the surface sufficiently so that the only sign of this igneous activity which remains on the surface of today is the trap dikes, the lava-filled channels of ascent of the molten rock. The trap is absolutely unmetamorphosed and gives every indication of having solidified at quite shallow depth. Hence the conclusion is forced that the eruption occurred toward the close of the long Precambrian erosion period previously described, and since only a comparatively slight amount of wear followed, that these dikes are of very late Precambrian age; in fact it is by no means impossible that they may be as young as the early Cambrian.

If we could follow these dikes down into the earth beneath the surface of today, no doubt we should find that they lead upward from underground masses of trap of considerable size, quite analogous to the batholiths of the earlier granites.

Close of the long period of erosion

Eventually this long period of surface wear on a land area drew to a close, and for a time the history of the region became of very different nature, in other words instead of loss of surface material it began to gain it in the shape of deposits on the old, worn land surface. These deposits blanketed and preserved the old erosion surface, and since the wear of today has come down to that precise horizon over parts of the district, and the overlying deposits are being peeled away from it, it is returning to daylight with precisely the characters it possessed when it was buried and preserved ages ago. Seldom does a district reveal so abundant and clear evidence of the nature of an old fossil land surface. It is clear from its study that long wear had reduced it to a surface of comparatively slight relief, showing that no considerable elevation of the region occurred during the latter portion of the long erosion interval. Nevertheless it is very far from being a plane surface, but is of considerable minor relief, of low ridges and shallow valleys, or of low knobs and basins, the depressions eaten out on the weaker rocks, chiefly the Grenville limestones and some of the schists, while the more elevated ridges and knobs are due to the resisting qualities of the Grenville quartzites and of many of the igneous rocks. The knob structure is practically confined to the igneous rock areas, chiefly in the Laurentian gneiss.

While the region therefore is quite rugged in a mild fashion, the extreme differences in altitude are but slight. One hundred feet is about the measure of difference. Seldom does the difference in level between valley bottom and ridge crest reach that figure, and rarely does it exceed it. This is a small difference, considering the wide variation in resisting power to wear which the various rocks present and is indicative of a long period of wear under comparatively stable conditions of level.

Paleozoic sediments

Potsdam sandstone. A change in conditions followed and deposition of sand commenced upon this old land surface. It naturally began on the valley bottoms and encroached on the ridges only as the valleys filled. The old limestone surfaces were pitted by small depressions, and were somewhat intersected with widened joint cracks also, and in these the first materials collected, sometimes full of coarse fragments of resistant thin quartzite bands or

granite dikes such as are found nearly everywhere in the Grenville limestones, sometimes containing only sand. There is comparatively little basal conglomerate in the district back from the river, but there, both on the mainland of the Alexandria quadrangle and on Wellesley and Grindstone islands is an exceedingly coarse conglomerate, from 10 to 20 feet thick, full of coarse cobbles derived from the ponderous and resistant Grenville quartzite of the vicinity.

Except for these conglomerates the formation is everywhere a sandstone and mostly pretty thoroughly cemented, the cement being chiefly of silica. Its colors are red, brown, yellow, white, and rarely black. Its thickness over the immediate district will scarcely exceed 100 feet, and it thins out toward the west and south. The deposits of sand began forming first in the Champlain region and gradually worked their way westward, being deposited in a shallow trough or basin whose axis roughly coincided with the modern St Lawrence axis, so that hereabouts we find simply the thinned western edge of the formation. As its thickness here is substantially equal to the difference in altitude between the ridge crests and valley bottoms of the old erosion surface upon which it was deposited, it follows that it varies rapidly in thickness from place to place and was but scantily deposited upon the elevations, some of which it utterly failed to overtop.

It is not known whether or not the formation in its entirety is a marine formation. The sparse fossils indicate such origin for the upper beds with comparative certainty, but many things about the remainder of the formation suggest a land surface and an arid climate as the conditions under which the accumulation took place.

Theresa dolomite. A change in conditions ensued and deposit of dolomite began. Some sand was still supplied from the neighboring land however, as the dolomite is everywhere sandy, and at first the supply was from time to time in excess, so that layers of coarse weak sandstone alternate with those of dolomite. Hence there is a gradation from one rock to the other instead of a sharp boundary between the two. The greatest thickness of the formation within the area mapped does not exceed 35 feet, though its original thickness may have been somewhat greater. The thickness increases eastward and diminishes to the west and south as was the case with the underlying sandstone. The waters were more fitted for the existence of life and the fossils are more abundant than in the sandstone, but unfortunately conditions for their preservation have not been favorable.

The Theresa formation followed close after the Potsdam and they were laid down in a trough or bay along the present St Lawrence line which was landlocked on the north, south and west. The depression of this trough originated to the eastward, where the deposits are thickest, and deposits did not commence in the immediate region until late in Potsdam time. The extreme western extremity of the bay can not have lain many miles west of the immediate region at the time of its greatest expansion. Then it commenced to contract and slowly work back eastward.¹

Uplift following the Theresa. This tendency to contraction of the trough, caused by slow uplift of the land, seems to have continued until the bottoms of both the St Lawrence and the Champlain troughs had been raised above sea level, so that all the northern portion of the State was above that level. After a time renewed depression followed, apparently commencing simultaneously on the west, south and east sides of the Adirondacks, and the Tribes Hill phase of the Beekmantown formation was laid down. This was followed by uplift which began at the west and worked eastward, bringing the west and south sides of the district above sea level, while subsidence still continued in the Champlain valley, in which a large thickness of later Beekmantown rocks was deposited. This Tribes Hill subsidence came in on our district here from the south and its deposits constitute the upper portion of what is mapped as the Theresa formation. Until the Beekmantown formation along the St Lawrence valley has received further study we can not say whether the Tribes Hill limestone extends east of the Frontenac axis or not. Our present view is that it did not, and that the Beekmantown of the St Lawrence valley represents the higher portion of the formation, deposited in a trough which extended westward up the valley from the Champlain basin. This depression did not carry the immediate region below sea level. The district tilted to the southwest and received a thin edge of Tribes Hill deposition, then rose and was tilted back to the eastward, though not sufficiently to allow the later Beekmantown sea of the district to the east to quite reach it.

¹ Since the field work was completed and this report written, work elsewhere in New York has shown that probably the Theresa formation, as here mapped and described, is in reality composed of two probably unconformable formations, of quite different ages, and that the name should be restricted to the lowermost of these, the upper being of lower Beekmantown age, and equivalent to what we are calling the Tribes Hill formation in the Mohawk valley. The matter is discussed in more detail on a later page.

In the Champlain valley the Beekmantown rocks are overlaid by the Chazy limestones. There is evidence there of a break between the two formations and the Chazy has a basal sandstone. The Champlain Chazy trough also had a westerly bay but it never extended as far west as the district under discussion. During the long time interval therefore during which Beekmantown and early Chazy sedimentation was transpiring in the subsiding Champlain trough, the district here was above sea level and experiencing wear rather than receiving deposit. Considering the length of the interval the amount of erosion which it suffered was but slight, arguing for low altitude and gentle slopes for the land. Broad, shallow valleys were cut in the surface of the Theresa limestone but the depth of cutting seems never to reach the base of the formation.

Pamelia (Stones River) limestone. The Chazy basin of the Champlain, St Lawrence and Ottawa valleys was landlocked to the south and west during lower and middle Chazy time. During this time interval, however, other and larger basins of subsidence and deposit existed to the south and west but completely separated from the Chazy basin. Both the rocks and the contained fossils therefore differ from the Chazy and the formation is known as the Stones River. Notwithstanding difference of name the two formations represent substantially the same time interval.

As Chazy time passed on, the large Stones river basin to the southward encroached northwardly and toward the latter part of the interval had become sufficiently extended to submerge the immediate district. The slow warping of the land which brought about this subsidence gave the district a wholly different direction of slope. In Potsdam and Theresa times it had sloped to the northeast and formed part of the extreme westerly end of the subsiding trough. It now came to slope to the southwest, was invaded by the sea from that direction, and to the northeast lay a land area which separated it from the Chazy basin beyond. Though the district was covered by the waters of both marine invasions it was near the shore line in each case and received only comparatively thin, marginal deposits, representing only a small fraction of the entire thickness of the formations concerned. Hence in a broad way it is true that what had been the western shore of the earlier sea became now the eastern shore of this later western sea, or that the general district formed an axis or pivot from which the land tipped now in one direction

and now in the other, remaining throughout an area of small subsidence.

The deposits laid down in this depression are of upper Stones River age and the name of Pamela limestone is proposed for this New York phase of the formation. Locally it is known as the "blue limestone" though the local name commonly includes the overlying Lowville limestone as well. A thin, basal sandstone appears, after which follow alternating black, blue and gray limestone beds, then the black limestone disappears and white, earthy limestone alternates with the others. During the deposit of this upper portion the waters seem to have become shut off from the open sea, by the development of some shoal or reef as a barrier, and in the lagoon thus formed water lime was deposited, the waters often evaporating sufficiently to expose wide mud flats which dried and cracked under the sun's influence. The marine fauna found these conditions uncongenial and disappeared, though returning from time to time for a brief space with fresh influx of water from the sea outside. Deposition became intermittent and eventually ceased and some slight wear occurred locally.

Lowville, Watertown and Trenton limestones. Subsidence then recommenced, and upon this slightly worn Pamela surface the dove-colored limestones of the Lowville formation were laid down. The Lowville submergence was somewhat more extensive than the Pamela, since the former appears in the Mohawk valley while the latter does not. And though both formations occur along the Black river valley it seems probable that the Lowville sea encroached more widely upon the borders of the land which lay to the eastward.

The Lowville is a quite pure limestone for the most part, and carries a much more abundant and varied marine fauna than do any of the older rocks. Above it lies a more massive, cherty limestone, separated from the main mass of the Lowville by an unconformity, which we are calling the Leray limestone, and classing as an upper member of the Lowville. Above this, also with an unconformity between, comes a similar massive limestone, without chert, which we are proposing to call the Watertown limestone. The Watertown and Leray limestones taken together are known in the region as the Black River limestone, the Leray being locally more like the Watertown than like the Lowville in character. Because of this, and because of their small thickness (about 10 feet each), we have felt constrained to map them together. They carry

an abundant marine fauna, the large cephalopods being especially conspicuous.

The Watertown limestone is unconformably overlain by the thin bedded limestones of the Trenton. The time interval between the Lowville and the Trenton was a considerable one, but the surface exposures of these rocks in New York are so near the old shore lines of the time, that the deposits exposed represent the interval very imperfectly. The shore line was one of many and frequent local oscillations, and the rocks which have, of late years, been classified as Black River limestone, represent very different parts of this general interval.

The Trenton limestone is abundantly fossiliferous and has a thickness of 400 feet or more in the immediate region, exceeding the combined thickness of the Potsdam, Theresa, Pamela, Lowville and Black River together. Found on all sides of the Adirondacks, and with large thickness everywhere, the Mohawk valley excepted, large subsidence is shown, with probable great encroachment of the waters upon the Adirondack island, much diminishing its size.

As Trenton time drew to a close fine muds commenced to appear in the waters, brought in by currents from the northeast, and in slowly increasing amount. Hence the limestones become impure and grade upward into black shales, at first strongly calcareous, later on lacking lime. This change came on the region from the eastward, hence shales were forming there while limestone was still being deposited on the west. But the change to mud deposit spread slowly over the whole region and the Trenton is found everywhere to be overlaid by the black Utica shales. This Utica submergence seems to have been the most extensive in the State's geologic past, and it is quite possible that the entire Adirondack island was submerged. If so it seems to have been the last time that such was the case, as it was the first.

Above the Utica lie the lighter colored shales and shaly sandstones of the Lorraine formation, the combined thickness of the two shale series being several hundred feet. While neither formation is found within the limits of the area mapped, in which the lower Trenton is the youngest rock found, yet they outcrop in great thickness on the Watertown quadrangle and reach to within 6 miles of the south margin of the Theresa sheet, and it seems quite certain that they were originally deposited over part, and likely all, of the district mapped, and are now absent from it because of subsequent erosion. It is even probable that the Oswego and Medina sandstones, thick sand formations which overlie the Lorraine shales,

and whose present northern margin of outcrop is distant but 15 miles from the map limits, may also have been somewhat deposited within it. Certainly the sandstone extended originally farther north than now, but just how far no one can say.

The deposit of these sands indicates a shallowing of the waters over the region, following which it was uplifted above sea level. Thenceforth in the main, throughout the millions of years which have since elapsed, the district has remained a land area. It is quite possible that the succeeding Siluric and Devonian seas, whose waters covered central and western New York, may have washed over this district, and laid down thin deposits. But if so, every trace of such deposits hereabouts has disappeared through erosion, so that no certainty can be arrived at in the matter.

As a result of the various oscillations of level which the region has undergone the rocks described have been changed from their original nearly horizontal position, into a series of low folds. This folding seems to have commenced early and to have been continued on various occasions, since there is some evidence that the Potsdam and Theresa formations were somewhat folded before Pamela deposition began. Subsequently more folding took place, involving the entire series, and though the folding is gentle its topographic expression is plain.

The principal folds have axes which trend northeast-southwest, but there is also present another set with northwest-southwest trend, or at right angles to the first set, whose arches and troughs are thus folded up and down, producing gently elevated domes and depressed basins, the former where the arches of the two sets cross, and the latter at trough intersections. Many of the outliers shown on the accompanying geologic maps owe their existence and preservation to this folding.

Subsequent history of the region

But little that is definite can be said of the history of the district during its long existence as a land area following the deposition of the rocks previously described. It seems quite certain that the amount of rock worn away from the surface during this time is slight, considering the length of the time interval, and that therefore the land has seldom had any considerable altitude. Where the entire thickness of overlying rocks has been worn away and the Precambrian exposed at the surface, as is the case on parts of the Theresa and Alexandria sheets, it seems quite certain that not

over 3000 feet of rock thickness has been removed, and likely considerably less. Since the overlying rock has been worn away down to the Precambric over only a small portion of the whole district, it follows that in the remainder the erosion has been less than the above amount by the remaining thickness of such overlying rock. The character of the district to the south of the map limits however indicates an uplift of the land of *comparative* recency to the amount of several hundreds of feet, and the present-day stream valleys of the region have been worn down below this old level in this comparatively recent period. This relatively considerable recent elevation and erosion makes still more emphatic the necessity for assuming slight elevation of the region during the much longer interval which preceded it. As compared with much of the district surrounding it this area has been one of but slight changes of level during its past history. While in their early history these surrounding districts were submerged and subsiding, allowing thick accumulations of deposits, this area subsided less and received but scanty deposit. Only during middle and late Lower Siluric time, during Lowville, Trenton, Utica and Lorraine deposition, was it a district of considerable subsidence and deposit. In its subsequent history as a land area it seems to have been one of but small uplift as compared with much of the adjacent region.

As has been stated, in the comparatively recent past the district experienced uplift to the amount of several hundred feet. Prior to this it had been worn down to a surface of comparatively slight relief. The uplift gave the streams power to deepen their valleys by an equivalent amount, and the processes of wear which have given the present relief to the region were set in motion. Then, as now, the Black river was the chief stream of the neighborhood, and perhaps turned west into the Ontario lowland as it now does; but the lake was not in existence then, nor was the drainage of the lowland to the eastward, but the Black river flowed through it in a westerly direction, receiving many tributaries from the north and the south. There were also easterly flowing waters in the district, however, the beginnings of streams which drained down the St Lawrence valley. But the St Lawrence of the time had its sources in the immediate region, and contained no waters coming from farther west, the divide between the easterly and westerly flowing waters being here, crossing the present St Lawrence in the Thousand Island region on the hard rock barrier which the Precambric rocks furnish. On the New York side the divide can be traced across the Clayton, Alexandria and Theresa quadrangles in a south-

easterly direction, with sharply cut ravines heading against it on both sides, marking the extreme heads of the small streams which flowed on the one hand northeast to the St Lawrence, and on the other hand southwest to the Ontario drainage. On the Clayton quadrangle the French creek valley belongs to the former, and the Chaumont river valley to the latter category; on the Alexandria most of the country was on the St Lawrence side of the divide, the valleys of Crooked creek, Cranberry creek, Butterfield lake-Black creek, and the valleys now occupied by the other lakes belonging there, while Mullet creek valley drained the other way; on the Theresa the valley into which the Indian river breaks at Theresa village seems to belong to the easterly drainage, while the remainder of the valleys on the quadrangle carried water to the westward drainage.

The valleys excepted, the prominent topographic feature of the region is the rock cliffs, usually low, which mark the edges of outcrop of the various formations, and which owe most of their present relief to the wear which followed the considerable uplift. In general, each rock formation of the region is somewhat less resistant to wear than the formation beneath and somewhat more so than the formation above. Hence the overlying formation tends to be slowly stripped away from that beneath, which yields more slowly and, because of the nearly horizontal attitude of the rocks, remains as a comparatively flat terrace, above whose level stands the receding front of the overlying formation, while in the opposite direction the lower formation has its terrace terminated by a similar front which drops down to the level of the formation next underlying. Each formation then shows a receding front of the sort, the Theresa above the Potsdam, the Pamela above the Theresa and so on. Because of the greater thickness of the formations the Trenton and Pamela fronts are the highest and the most conspicuous as topographic features. The Trenton front only gets within the map limits in the extreme southeast corner of the Theresa sheet, but the Pamela front can be followed as a cliff of more or less prominence across the Theresa and Clayton quadrangles, until the formation is lost beneath the river. This is the kind of topography invariably produced when a district of nearly horizontal rock formations of varying resistance is being worn down, but the general type is magnificently illustrated in the region here.

The Pleistocene¹

During the geologic periods of the Devonian, Carboniferous and Permian, and the Mesozoic and Cenozoic eras, each millions of years in length, our area was doubtless always above the sea and subjected to the wasting processes of atmospheric erosion.

Closing the immensely long time of erosion and bringing the history down to the present time, three geologic episodes are conspicuously recorded in the existing surface features. The first of these episodes was the burial of the entire area for some scores of thousands of years under the Labradorian ice sheet with its grinding flow. The second was the burial for further thousands of years under glacial and marine waters that immediately succeeded the latest of the ice bodies. The third episode is the present time, a restoration of the subatmospheric conditions of erosion, which has endured, probably, some 10,000 or 20,000 years.

It is now comparatively certain that during the long geologic history great changes of climate have occurred. The idea, once prevalent, that there had been during all geologic time a steady lowering of temperature and refrigeration of climate from a primitive condition of excessive heat and moisture is wholly an error. The oldest rocks of sedimentary origin contain records of glaciation. In the Permian, ice work was great and wide-spread, and glaciation was probably frequent during past time in elevated regions now eroded. The warm climate of the middle Tertiary was followed by glacial cold in northern lands, and all of New England, New York State and the basin of the Great Lakes was deeply buried under successive sheets of ice which had their origin or centers of accumulation in Canada and Labrador. The peculiar effects of the glacial invasions will be described in a later chapter.

Following at least the latest of the ice sheets the entire area under description was buried for some thousands of years beneath waters held up to high levels by the glacier acting as a barrier across the St Lawrence valley. The shore features and deposits characteristic of lake action are found over the region.

During the time of the ice retreat this portion of the continent was lower, or nearer ocean level, than at present, and when the ice barrier melted away in the St Lawrence valley, the glacial waters (Lake Iroquois) were drained down to sea level, and the north and west sections of our area were long swept by oceanic waters, a branch of the Champlain (Hochelagan) sea called

¹ By H. L. Fairchild.

Gilbert gulf.¹ The shores of the glacial and sea level waters are conspicuously preserved in many places, and specially in Jefferson county immediately south of the area; while their sediments occupy the valleys [*see* pl. 29].

The slow tilting uplift of this part of the continent finally raised the Thousand Islands district above the ocean level and then Lake Ontario was initiated. The uplifting has continued until the outlet and lake are now 246 feet above tide.

As the lake and marine waters were slowly drained away from the gently sloping surface of the area the storms and streams resumed their briefly interrupted work, and for a few thousand years they have again been gnawing at the rocks and land surface with important effects.

THE ROCKS²

Precambrian rocks

The Precambrian rocks of northern New York, as at present known, may be most conveniently classed in four groups, (*a*) a series of old sediments or rocks laid down under water, the Grenville series; (*b*) a series of granitic gneisses of igneous origin, which cut the Grenville sediments intrusively and hold abundant inclusions of them and which, in so far at least as the immediate region is concerned, are correlated quite confidently with the Laurentian granite-gneisses of Canada; (*c*) a series of somewhat younger igneous rocks which cut and hold inclusions of both the preceding groups, which have a great development in the eastern Adirondacks but occur in less force in the immediate region, and which consist of anorthosites, syenites, granites and gabbros, the last three of which occur here in masses of usually small size; and (*d*) of much younger igneous rocks, of late instead of early Precambrian age, which appear as dikes of diabase or trap, and which have some development in the region, though less abundant than in the eastern Adirondacks.

The Grenville sediments are the oldest known rocks of the region, and the fact that they are water-deposited rocks necessitates belief in the existence of a floor of older rocks on which they were laid down. No certain trace of this old floor has ever been discovered in New York, and though it is possible that fragments of it may be contained as inclusions in the granite gneiss, we are as yet unable to distinguish such, if present, from

¹ Gilbert Gulf (Marine waters in Ontario basin). Geol. Soc. Am. Bul. 17:712-18.

² By H. P. Cushing.

the similarly situated inclusions of the Grenville rocks themselves. The same conditions prevail in general over the much more extensive Precambric areas of eastern Canada. Recently, however, Miller and Knight have announced the discovery, in central Ontario, of a basement to the Grenville formation, Grenville limestone being found resting on an ancient lava flow, whose surface is thought to show signs of slight previous wear.¹ Miller and Knight correlate this old lava, or greenstone, with the oldest known formation of the upper lake region, the Keewatin, which consists mainly of greenstones, old lava flows and beds of fragmental volcanic materials. There are present, however, some associated sediments, and Miller and Knight regard the Grenville as of Keewatin age. These are most important results and if future work fully establishes these correlations, it will follow that the Keewatin has steadily increasing sedimentary content and less and less volcanic material as it is followed eastward. By the time New York is reached the greenstones have entirely disappeared, so far as is known. At least no rocks similar to them have ever been discovered in the New York Precambric. It should also be stated that Adams is not disposed to accept the reference of the Grenville to the Keewatin on the basis of the evidence yet in hand, believing a reference to the next overlying group, the Huronian, to be more probable.²

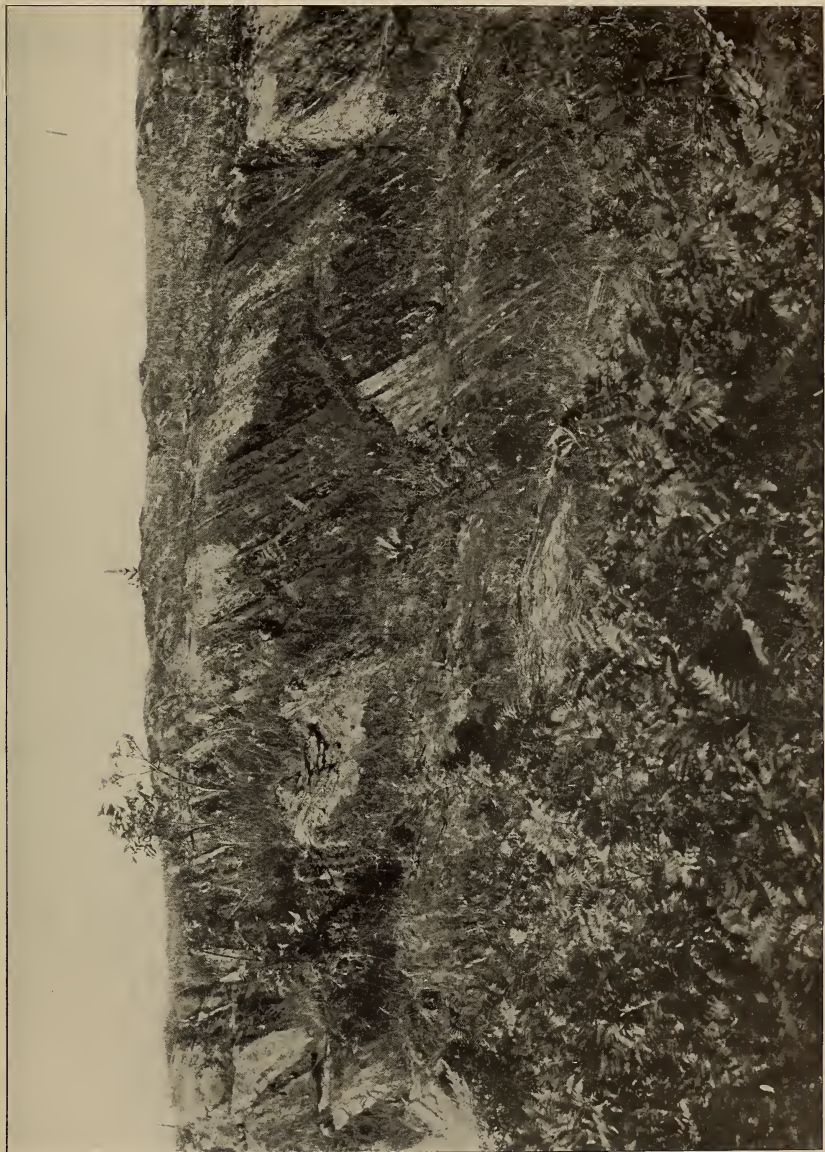
However this may be, the difficulty of accounting for the disappearance of the old floor of deposit is not helped, but merely pushed a stage further back. Miller and Knight speak of only slight erosion of the old lava flow prior to the deposit of the Grenville limestone upon it. It is of course possible that this may be merely an interbedded flow of Grenville age and itself rest upon other Grenville sediments. But in any case these Keewatin lava flows and fragmental deposits are surface deposits and require the presence of a floor on which they were laid down just as much as do the Grenville sediments; but no such floor to the Keewatin is known. It is always found resting on Laurentian granite gneisses of igneous origin, or upon yet younger igneous rocks which invaded it from beneath in molten condition, cut it to pieces, and apparently engulfed and assimilated its basal portion along with the floor upon which it rested. Precisely these same conditions prevail in general in respect to the Grenville and its former floor.

¹ Bureau of Mines, Ontario. 16th An. Rep't, pt 1, p. 22-23.

² Adams, F. D. Jour. Geol. 16:634-35.

In New York then the Keewatin volcanics are wholly absent, except for the possibility that some of the amphibolite inclusions of the granite gneiss may be greenstone fragments considerably metamorphosed. Otherwise the Grenville sediments are the oldest recognized rocks, and they occur in patches or in belts of varying size and extent, resting on, surrounded by, and all cut to pieces by the granite gneiss and the yet later intrusions.

Grenville rocks. These rocks as originally deposited consisted of limestones, shales and sandstones, both pure and in their various transitional phases. In all probability too there was some intermingled volcanic material, though the presence of such material has never been definitely proved for the New York Grenville. The rocks have been profoundly changed in character since their formation, in part owing to great compressive stresses which operated throughout the district, and in part owing to the heat and pressure furnished by the great igneous intrusions, and also to the mineralizing agents to which these gave rise. These changes moreover were brought about early in Precambrian time and under deep-seated conditions. As found today the rocks are wholly crystalline, having completely recrystallized under the severe conditions to which they were subjected, with loss of all traces of their original clastic textures. In their stead there has been developed a cleavage, or foliation, due to parallel arrangement of the mineral particles on recrystallization. The old bedding planes of the rocks can still be made out, however, in places where the composition of the original rocks changed, as where limestone was succeeded by shale or by sandstone, and from these old bedding planes it can be seen that the development of the foliation is parallel in direction to them. The original limestones have become coarse, white crystalline limestone or marble, the sandstones are now hard, glassy quartzites, while the shales and impure limestones and sandstones have become schists and gneisses of many types, while yet other varieties are contact rocks whose nature is due to action of the intrusives upon adjacent sediments. The variety of rocks is so great that it would be a hopeless task to attempt to map them all upon any such scale as that of the maps which accompany this report. One or more beds of very thick limestone occur, such as that along the Indian river northward from Theresa, or that along Butterfield lake; thick quartzites also occur, especially on Grindstone and Wellesley islands; a large thickness of green schists of a peculiar type is found to the south



Grenville green schists near the St Lawrence at Forsters landing. Alexandria Bay quadrangle, $2\frac{1}{2}$ miles south of Chippewa Bay. Strike of schists n. 25° e. and dip 55° e. View looks north. H. P. Cushing, photo, 1908

and southwest of Alexandria Bay. But the bulk of the Grenville of the district occurs as a great schist series, with rather rapid alterations of varying types in bands of no great thickness, and interbanded with these are thin limestones and quartzites. After trial of various methods it was found that, on a map of this scale, and with rocks of this rapidly varying character, no further subdivision of the Grenville was possible than a separate mapping of the thicker limestone and quartzite beds, the entire remainder being mapped singly as a schist formation. It is feared that even this amount of subdivision has resulted in a map too complicated for easy use.

It was hoped that the careful, detailed mapping attempted might solve the problem of the order of superposition of the rocks and give some definite idea of the thickness of the whole. The outcome was disappointing and neither hope distinctly fulfilled, though some results were obtained. The mapping therefore is purely lithological and not on a structural basis, as it was endeavored to make it.¹

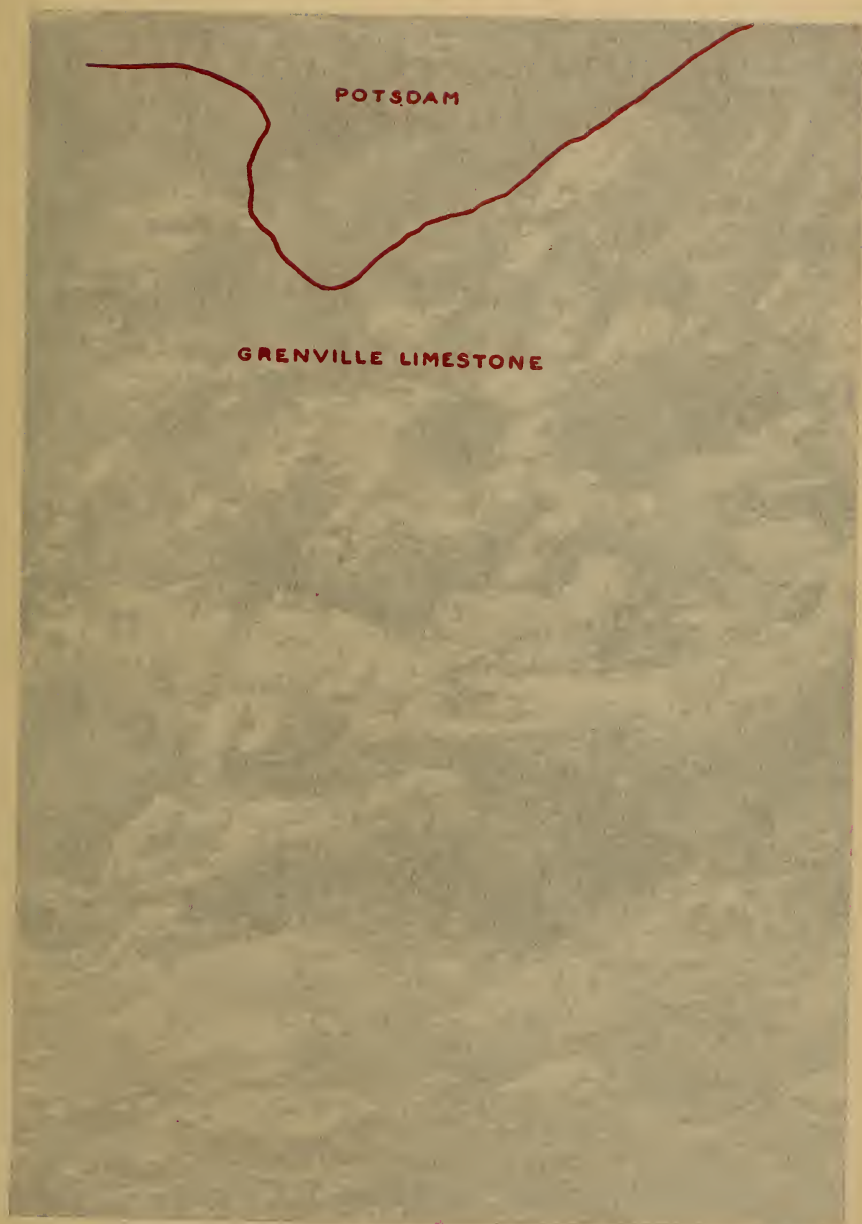
The average trend, or strike, of the Grenville rocks is to the northeast. The direction to be sure varies considerably, swinging around to the north on the one hand, and to the east or even somewhat to the south of east on the other, yet these variations are not sufficiently frequent to offset the general statement. The dips are usually high, seldom less than 45° and frequently very steep or even vertical [pl. I, 2]. Over the greater part of the area north dips prevail, but are replaced by south dips throughout a belt of country from 2 to 3 miles broad across the Alexandria quadrangle. This is certainly indicative of folding of large magnitude, and is corroborated by the fact that in many localities minor folds are clearly to be made out, and intricate minor puckering and corrugation. Of the two broad limestone belts within the map limits, the one along the Indian river north of Theresa, and the one about Butterfield lake, the former has a north, and the latter a south dip, and in each case the breadth of outcrop across the strike is about a mile. With the steep dips a thickness of about 4000 feet is indicated for this limestone in each case, and it is therefore conjectured to be the same thick stratum, with the structure synclinal. If this be the true interpretation then the complex of quartzite and

¹ Though the work was of vastly more detailed character than the earlier work of Smyth on the same rocks, it will be seen by any one who will take the trouble to compare the two maps that the basis for the subdivision of the Grenville is substantially the same in each case. No more convincing testimony could be given as to the high class character of Smyth's work.

schist, which lies between the two in the southeast corner of the Alexandria sheet, and which consists of alternating bands of quartzite and various schists of no enormous individual thickness, but which, taken together, must have a thickness of several thousand feet, rests upon the thick limestone and is the youngest portion of the Grenville exposed within the map limits. To the north, and beneath the limestone would come the great complex of green schists and impure greenish limestones which there occurs, which have steep dips and must have large thickness, at least as great as the two previous groups, and likely greater. Doubt is thrown, however, upon this interpretation by the fact that the rocks which follow the thick limestone to the south, on the Theresa sheet, differ considerably from the green schist series which follows it to the north on the Alexandria sheet, and yet according to this interpretation the two should be identical, representing the series directly beneath the thick limestone. Each does consist of schist, calcareous schist, and thin limestone bands, with an occasional thin quartzite, but the Theresa rocks are not of this distinct green schist type. A possible answer to this objection may be found in the fact that, notwithstanding a rather intimate acquaintance with the Grenville series all over northern New York and in parts of Canada, the writer has nowhere else seen the counterpart of this green schist series. It is in rather close association with the Picton granite, which was richly supplied with mineralizing agents, and is everywhere cut with numerous dikes from this granite, so that its peculiar characters are thought to be largely, or wholly attributable to this contact action, and thus explained as due to these local conditions. If this be not the explanation there seems no alternative but to regard the two thick limestones as separate beds, thus largely increasing the thickness of the section, already great. If the structure is thus correctly interpreted, a thickness of at least 20,000 feet is indicated for the Grenville of the district, and this is a conservative estimate. If the structure is not synclinal this thickness must be nearly doubled.

This matter will be discussed somewhat more in detail on a later page. The purpose here is simply to give an outline of the supposed Grenville succession and some idea of the great thickness of the series.

Limestones. The general Grenville limestone of the district is a coarsely crystalline and quite pure white marble, only sparingly charged with other minerals. The great bulk of the rock of the thick belt, or belts, just referred to, consists of 95% or upward of



Small fossiliferous quartz in Grenville limestone at Tolson near the base. The limestone bed is a thin one in the general schist series and the quartz face is shown in fig. 10, page 72. At the upper part of the zone is a thin bed of sandstone with irregular contact with the limestone, and showing one or two scattered nodules consisting of these contacts filled with small common crystalline sandstone. H. P. Cushing, photo, 1907.



POTSDAM

GRENVILLE LIMESTONE

Plate 2



Road metal quarry in Grenville limestone at Theresa near the falls. The limestone bed is a thin one in the general schist series and the quarry face is down the dip, here 75° . At the upper part of the cliff is Potsdam sandstone with irregular contact with the limestone, and showing one of the depressed pockets characteristic of these contacts, filled with weakly cemented calcareous sandstone. H. P. Cushing, photo, 1907

calcite. Toward the edges, however, the rock becomes much less pure, and at times the same thing happens in the near vicinity of the igneous intrusions, large and small, which repeatedly cut through it. This is by no means the invariable rule however. In the case of the thin limestone bands which occur in the general schist series [pl. 2] there is much less pure limestone, since these bands show the same impure borders as does the thick belt, leaving only a small central thickness of the purer rock. In this pure rock occasional graphite scales, flakes of brown mica (phlogopite) and occasional small crystals of white pyroxene (diopside) are the usual accessory minerals and in very small amount. Others occur, but very sparingly. These rocks must originally have been extremely pure limestones, slightly contaminated with organic matter, which now appears in the form of graphite.

The impure limestone of the area is owing to two distinct causes. Certain thin bands of impure limestone in the schist series, and the impure borders of the otherwise pure bands seem unquestionably owing to original deposit as shaly or sandy limestones, forming gradations between the pure rock and the overlying and underlying shales and sandstones. Hence on recrystallization a much smaller percentage of calcite and a much larger one of other minerals has resulted. The other cause is the interaction of the limestone with igneous rocks, producing what are known as contact rocks, in which certain added ingredients are supplied to the limestones from the igneous rocks and react with the limestone to form minerals which thus have a mixed origin. Such contact rocks are thus limited to the near vicinity of the igneous rocks.

The two most common kinds of impure limestone of the first type in the region are the quartzose limestones, and the pyroxenic limestones. Much of the marginal limestone seems to have been sandy, and even to have contained thin layers of fairly pure sandstone. This has recrystallized as quartz, partly in fine grain, forming a mosaic with the calcite, and partly coarser and in films and patches in the limestone. Each mineral at times contains inclusions of the other, they evidently recrystallized together, and the quartz evidently had the stronger crystallizing force. There is a considerable amount of limestone in the area which is a calcite-quartz rock, with little or no admixture with other minerals.

Even more common is the pyroxenic limestone, where the calcite is accompanied by a greater or less amount of a white or a light green pyroxene. This is prone to alter to serpentine, a dull green, greasy to earthy looking mineral, producing a mottled green

and white rock which is of common occurrence in the Grenville wherever known. In the writer's experience this is far from being true of the quartzose limestone which occurs in much greater force here than is customary.

Of the various Grenville rocks the limestones are much more yielding under compressive stresses than are the schists and quartzites, behave more like plastic and less like brittle bodies, and hence change shape more readily. As a result rocks which much resemble coarse conglomerates are a frequent feature in the Grenville limestone. Frequent dikes of granite traverse it, many of which are of slender width. Under compression these are brittle under conditions which are sufficient to cause flowage in the limestone, hence the dikes fracture, the separate fragments are somewhat shifted in position and limestone is squeezed in between them. The same thing takes place where thin bands of quartzite or of schist are present in the limestone, as is frequently the case. These fragments of granite, quartzite or schist weather less rapidly than the surrounding limestone, and hence project somewhat on weathered surfaces, with considerable increase in conspicuousness, and the separate fragments surrounded by calcite give an admirable mimicry of a conglomerate in appearance.

In addition to the normal white limestone frequent patches or streaks of gray or blue limestone also occur in association with it, which outwardly look much more like ordinary limestone. This is in line with the further fact that all the Grenville rocks seem somewhat less severely metamorphosed than is the case with the equivalent rocks to the eastward. Even the white marble has at times a grayish or bluish cast, and does not average as coarsely crystalline as the eastern Grenville limestone. On the other hand limestone of these characters is commonly not so pure as is much of the white limestone, and these gray or blue portions often occur in such situation as to suggest that they are contact effects of igneous rocks on the white limestone. In some instances certainly the white limestone changes to gray adjacent to an igneous rock mass of good size, and in others gray patches in white limestone occur in direct contact with granite dikes, an unlikely situation if they are really less metamorphosed portions of the white limestone. It is also true, however, that some of the gray limestone is very pure, that in some places it has no discoverable nearness to any igneous rock, and that in general the contact action of the igneous rocks of the district upon the limestone has been but slight, though with local exceptions to this statement. With such arguments in

mind it has seemed to the writer as though the weight of the evidence were in favor of the view that at least some of the gray and blue limestone was representative of the white in less metamorphosed condition, and if some, then likely all.

Nowhere else in northern New York has the writer met with Grenville limestone of this fine grained, darker colored type. A comparison is at once suggested with the district in Ontario recently described by Adams who has shown that a similar, though better marked change comes over the Canadian Grenville limestone when followed westward, a local development of bluish limestone in thin bands within the coarser white limestones.¹ The evidence seems to indicate that we have here in New York the first glimpses of a similar tendency.

The consideration of the contact effects which the various igneous rocks have had upon the limestones is deferred until the igneous rocks themselves have been described.

Quartzites. There are two belts of ponderous quartzites in the region, one on Wellesley and Grindstone islands, and the other in the district east of Redwood (Alexandria sheet). In both cases the quartzite is interbanded with various schists and amphibolites, in highly folded condition, so that the number of quartzite beds is uncertain, and whether there is more than one massive, thick quartzite can not be positively stated. There is certainly a considerable number of thinner bands. Unless our interpretation of the structure is wholly at fault, these two belts represent lines of outcrop of the same geologic horizon, and form the youngest rocks of the series exposed in the district. In addition to this main horizon there are also frequent quartzite bands found in the general schist series, and thin bands even occur at times with the limestones. The more prominent of such bands are indicated upon the maps.

The ponderous quartzites are the most resistant rocks of Precambrian age in the region, and since they are interbedded with schists which are far weaker, the districts where they outcrop are quite rugged topographically, as Smyth pointed out 10 years ago. The quartzite ridges tower abruptly above the narrow valleys eaten out along the schists.

Since the rock is an altered sandstone, recrystallized under heat and pressure, and since sandstones often range in composition from a high degree of purity to those which are quite impure, either shaly, or calcareous, it is but natural to find much variation in the rock from place to place. The thick bands are chiefly constituted

¹ Adams, F. D. Jour. Geol. 16:623-24.

of massive, coarsely crystalline quartz, running up to as high as 90% of the rock, though feldspars and accessory minerals are always present. The thinner quartzite beds are generally more impure, though containing layers of coarse, massive, quite pure quartzite. The impurer beds are often well foliated, consisting of alternate films of pure quartz and of other minerals, the former very resistant to the weather, the latter less so, so that on the weathered surfaces the contortions and puckerings of the complexly folded schist series are much more perfectly displayed than in any other rock type of the region. They are often very close jointed, especially near granite, weathering out into small blocks [pl. 3].

Much of the quartzite of the district is more or less permeated with brown, iron-stained spots, due to the weathering out of some mineral with iron in its composition. These spots vary greatly in abundance in different occurrences and different layers, and may have a fairly uniform distribution, or, in the foliated varieties, be confined to the films containing other minerals than quartz, giving a brown and white, banded rock. In some cases, notably those of the first type, the mineral removed seems to have been pyrite, a mineral of consistent occurrence in the quartzite; in other cases it seems to have been pyroxene, though even here probably oxidized pyrite was responsible for most of the yellow, iron stain.

In texture the rock shows great variation, ranging from the very coarsely crystalline, glassy rocks, down to varieties which have a finely granular make-up.

Next to quartz, feldspars form the most prominent mineral constituent, orthoclase, microperthite and oligoclase all occurring. Much variation in relative amounts of the two mineral groups is shown, but in the great bulk of the rock, quartz is in excess and usually greatly in excess. In some varieties white to light green pyroxene appears in quantity, when the feldspar retreats. There is considerable of such quartz-pyroxene gneiss in the region, the quartz usually constituting 75% of the rock. Light brown mica (phlogopite) is sparingly present in much of the quartzite, and some varieties become quite micaceous. Pyrite is a frequent mineral, as has been stated. Zircon and titanite are nearly always present, and at times fine needles of rutile are abundantly included.

Here and there in the region rocks are found which present a puzzling half way stage between quartzite and granite, so that they are likely to be classed, now with one rock, and again with the other, according as the observer comes upon them from quartzite, or from granite. In all cases where the relations could be worked

Plate 3



Grenville quartzite of the much jointed type showing its characteristic weathering. The Potsdam lies just above but shows poorly in the view. Locality near the south margin of the Alexandria Bay quadrangle, nearly 1 mile south of Crystal lake, by the roadside. H. P. Cushing, photo, 1907

out such rocks either occur along granite-quartzite contacts, or else are included in granite. They are apt to show close set, block jointing, like the quartzite. They have been found only in association with the granite gneiss. The field evidence seems to us strongly indicative of the fact that these are really intermediate rocks, in the sense that they represent quartzites in various stages of granitization; that the quartzite is being permeated, soaked and even digested by the granite. The character of the intermediate rock, the shading of the two into one another, and the field occurrence of the intermediate stages, all point to this conclusion, and seem incapable of explanation on any other hypothesis.

Amphibolites. The name amphibolite is a convenient, comprehensive term for a group of rocks of gneissoid habit and dark color, composed essentially of hornblende and feldspars, with often considerable amounts of biotite or pyroxenes, and with accessory minerals of which magnetite is easily chief, and quartz and garnet of frequent occurrence. In respect to origin, the rock has long been a puzzling one since apparently identically appearing amphibolite might be produced by metamorphism from either igneous or from sedimentary rocks of the proper character. In a multitude of localities in the Adirondacks it has been shown that gabbro intrusions (whose character and origin is rendered certain by a core of practically unchanged rock) are largely changed over into amphibolites, every step in the process being open to inspection. Similar relations have been shown in many localities in all continents. Also in the Adirondacks, wherever the Grenville series is exposed, bands of amphibolite of varying thickness are found so definitely interstratified with other Grenville rocks of unquestioned sedimentary nature, that there seemed no escape from the conclusion that the rock must have resulted from the metamorphism of a sediment; and amphibolite of such origin is equally of world-wide distribution. In addition it has recently been shown by Adams that amphibolite can also be produced on a large scale by the contact action of granite on limestone. Here are therefore three different modes of origin, and the rock may be either igneous, sedimentary, or a contact rock. Each occurrence of the rock must therefore be studied by itself, in so far as its origin is concerned. Amphibolite of all three types is present in our district.

Within the mapped area amphibolite has not the bulk and importance that it has in much of the Precambrian district adjacent. There is much of it present as inclusions in the granite gneiss batholiths and stocks, inclusions of much variation in size and in

abundance. Frequent bands of it occur within the Grenville series, but these are usually of no great thickness. There is but little of the rock present to which an igneous origin may be definitely assigned. There are small areas of such rock in the district north and northeast of Theresa, where a somewhat more heavily bedded amphibolite occurs, which holds much pyroxene in addition to the hornblende, and which seems to definitely cut the limestone with which it is associated. There are, however, amphibolite bands interstratified with the same limestone, and the mass has been severely deformed, with the production of flow in the limestone and the fracturing of the amphibolite into blocks, making one appear to cut and be included in the other, but this does not seem to be a case of the sort. In our experience amphibolites which result from the metamorphism of gabbro, usually contain pyroxene in quantity, while those originating from calcareous shales are more apt to be micaceous and lack the pyroxene, but this is far from being an invariable rule, and is only suggestive of origin, not demonstrative.

The amphibolites interstratified within the Grenville series, and regarded as metamorphosed sediments, calcareous shales or something of that sort, are mostly quite finely and evenly granular rocks, which have wholly recrystallized, and vary from very solid looking, dense rocks in which mica is but sparingly present, to very schistose, highly micaceous rocks, which rapidly break down under the weather. In most of these orthoclase feldspar is apt to predominate over plagioclase, and much of the rock contains some quartz, the micaceous varieties often considerable. The manner in which the variations appear is itself highly suggestive of metamorphosed sediments which differed somewhat in character from bed to bed. Some of the rock contains garnets, in some cases reaching large size, but they are exceptional rather than the rule.

The amphibolite of contact origin will be discussed under the general topic of contact rocks.

Schists. Under this heading are included a large number of rock types, so many that it seems hopeless to attempt to describe all, or many of them. No doubt they have diverse origins. Some of them quite certainly owe their present character to contact action, and no doubt contact action of varying kind, and in varying degree, is in large measure responsible for the great diversity of the group. Some of the rocks grouped here are no doubt igneous, and in their character distinctly suggest such an origin, though the proof is difficult to obtain.

A very common variety of Grenville schist, the so called "rusty

gneiss" with its characteristic yellowish tinge on weathered surfaces, is but sparingly present in our area here. In the district east of Redwood it occurs somewhat, as it does also to the northward of Theresa. It is a quartzose gneiss, usually containing the mineral "sillimanite" and holding pyrite in quantity, the easy decomposition of which is chiefly accountable for the weakness and the color stain of the rock.

There are reddish, acid gneisses which, so far as composition goes might be either original granites, or shaly sandstones. There are black and white gneisses, which are feldspar-pyroxene-quartz gneisses. There are very granular, dark reddish, weak, micropertitic feldspar-hornblende gneisses; gray, feldspar-hornblende gneisses, holding much pyrite and titanite; there are leaf-quartz gneisses, the quartz in coarse spindles or lenses, and with little other than feldspar in addition; evenly granular, white, spotted gneisses which are micropertite-quartz-hornblende rocks; garnetiferous, quartz-biotite gneisses, with but little feldspar and a lot of pyrite; quartz-feldspar-phlogopite gneisses with graphite; gneisses which somewhat suggest metamorphosed volcanic tuffs, though in no case has it been possible to demonstrate such an origin for them. Many of the rocks contain calcite, which at times has resulted from alteration and at times suggests itself as an original constituent. Graphite is a frequent mineral in many of the schists.

Nowhere in the district has a rock been found which at all suggests the greenstones of the Keewatin formation.

Belts of badly altered rock, considerably impregnated with iron, so as to constitute lean iron ore, occur within the Grenville schist belts, striking with the belt and apparently behaving like an integral part of the series. Fragments of one such belt are found in the granite of the Alexandria bathylith near Cranberry creek, and a prominent belt occurs east of Redwood, especially along the north side of Millsite lake. The rock is exceedingly weak, earthy looking, either red, or yellow brown in color, and has a considerable local use for road metal. It is so thoroughly altered that it is almost impossible to get any clear notion of its original character being simply a mass of clayey, alteration products, with considerable calcite, and the whole impregnated with hydrated iron oxid, chiefly the red oxid. There are fresher streaks and bunches here and there which appear to be granite gneiss. None of the so called "serpentine" rock, which is generally associated with the similar, but richer, belt of iron ore which runs through Antwerp

and Rossie, just east of our map, has been noted here, but with that exception there is a strong resemblance in the material.

Igneous rocks. *Gneissic granites (Laurentian)*. There are two extensive (bathylithic) masses of granite gneiss in the district, both of which are only in part within the mapped area. The western end of what we have called the "Antwerp bathylith" is exposed on the Theresa quadrangle, disappearing westward under a Paleozoic cover. The Alexandria bathylith, on the mainland and islands of the Alexandria quadrangle, seems of smaller size but also disappears under a Paleozoic cover, both eastward and westward, and passes across into Canada as well. There are in addition numerous smaller masses. It is highly probable that all are connected underground, and represent the upper portions of a great, underground mass of granite, underlying all of the Grenville of the district, except where cut away by the later intrusions.

That this granite came to its present resting place after the Grenville was deposited was pointed out by Smyth 10 years ago, and is shown clearly in a host of exposures. Dikes without number run out from the granite masses into the Grenville rocks, the granite is everywhere full of included fragments of the Grenville, and along the contacts between the two sets of rocks, the Grenville rocks have plainly been modified by the contact action of the intrusive.

The general rock is a quite acid, red granite, composed chiefly of feldspars (microperthite, microcline and oligoclase) and quartz, with small amounts of mica (both biotite and muscovite) and magnetite, and with zircon, titanite and apatite as accessories. Such rock does not appear especially gneissoid, though usually of rather fine and even grain, but in thin section it invariably shows much crushing, and a considerable amount of recrystallization. The rock is everywhere cut by its own aplite, pegmatite and quartz dikes, some of which are much coarser grained, as usual. Many of the granite dikes which penetrate the Grenville, especially the limestones, are coarser grained, and less mashed than the general rock.

In a minor way the rock of the bathyliths is quite variable, and that in two main ways, one apparently representing original variations in the rock, and one owing to relative abundance of inclusions and the effect of the granite on them. The rock varies from one which is almost wholly constituted of feldspars and quartz, to one which contains several per cent of mica, which

thus becomes a conspicuous constituent. The rock changes from deep red through lighter shades to nearly white. It varies also much in texture, from thoroughly solid looking, crystalline appearance to varieties which weather to a sugary, granular aspect.

As usual in the Laurentian, inclusions abound, and as usual the bulk of these are of amphibolite. Quartzite inclusions also occur, but infrequently, limestone inclusions never. The amphibolite inclusions are found everywhere but always most abundantly near the margins, where they abound. In fact a sharp boundary line between the granite gneiss and the adjacent Grenville rocks can not be drawn. In passing from granite to sediments the inclusions show steady increase in number until they come to constitute 50% of the rock, beyond which we find sediments cut by granite dikes rather than granite holding inclusions of sediments. This reduces boundary mapping to a matter of estimating equality or inequality in amount of the two rocks, or in drawing a boundary where no real one exists. An attempt, however, has been made to indicate, by convention, on the maps, the actual state of things found in the field.

The granite dikes usually represent the extreme acid state of the rock. The main mass averages less acid, chiefly because of the inclusions and of the attack of the granite upon them. In its preliminary stages this usually takes the form of an injection of the granite in thin sheets along the foliation planes of the amphibolite, the so called "lit-par-lit," or leaf type of injection, producing a banded rock of alternations of igneous and sedimentary material. Then, here and there, the granite breaks out from the foliation planes and spreads through the rock adjacent, forcing its grains apart by the injection of a thin film of granite between. This process becomes more and more pronounced, until much of the rock is broken up into a granular mosaic of particles cemented together by granite films, producing what may be called the mosaic type of injection, as distinguished from the leaf type. A fine example of injection of this type is shown in plates 4 and 5. The injected rock is not amphibolite, but is green schist, a closely related rock, and the type of injection is identical. As a further stage, in both types of injection, the sharp boundaries become blurred, and this shading of the two rocks into one another becomes more and more prominent until finally rocks result which seem unquestionably to be due to the complete digestion of the amphibolite by the granite, gray gneisses of distinctly intermediate composition. As would be expected

these more advanced stages are usually found in the case of inclusions away from the near vicinity of the border.

We have not, up to the present time, definitely classed any of the granites of northern New York as of Laurentian age. Just across the border in Canada however, where the rocks are identical, this term is definitely applied to the granite gneiss of the bathyliths which invaded the Grenville series from beneath, broke it up into disconnected belts and patches and destroyed all trace of its floor. The absolute identity of the rocks and their relations, leads us to apply the name here to the granite gneiss bodies with much confidence in the wisdom and propriety of the correlation. Whether these Laurentian granites are recognizable, however, over any considerable part of the Adirondack region, in distinction from granites of later date, is a much less certain matter, though we believe it to be the case. It is thought for example that what we have called the Saranac gneiss in Clinton county, and the Long Lake gneiss of that quadrangle, are in all probability of Laurentian age.

Theresa syenite. This comparatively small intrusive mass lies to the southward of Theresa, in a valley floored by Precambrian rocks, but walled in by Potsdam on all sides. It is somewhat less than 2 miles in length and with a breadth of less than half a mile, so far as the exposures go; at the south it may have greater breadth underneath the Potsdam.

The general rock is of medium coarseness and granitic texture, though always with evidence of mashing and granulation, and of gray to greenish color. Most of it is chiefly made up of feldspars. It resembles in high degree the common greenish, augite syenite of the Adirondack region, is unhesitatingly classed with that, and is the only representative of that rock type within the mapped area. Like it, this rock is quite variable, becoming red and granitic looking on the one hand, and more basic with increase of black minerals on the other. Near the border some varieties become feebly porphyritic.

Microperthitic feldspar is always the chief constituent of the rock. Some oligoclase is always present. Quartz varies from some 15% in the more granitic, red varieties, down to complete absence. Augite is the most prominent black mineral in the ordinary rock, with biotite usually and hornblende sometimes sparingly present; magnetite, apatite, titanite and zircon are the chief accessories, the apatite usually quite prominent, another feature which the rock has in common with the general Adiron-



Grenville green schists intimately cut by granite. Forsters landing, by roadside not far from spot shown in plate 1; looking east. Height shown is about 10 feet. The schist shows dark and the granite white. The granite is injected along the foliation planes of the schist and then ramifies out into the intervening space, separating the schist into mosaic blocks or grains. Only the coarser of these show well in the view but the broader white bands are the same mixture on a small scale. This is regarded as the initial step in the process of the digestion of the schist by the granite. H. P. Cushing, photo, 1908



Upper figure. Hand specimen of the green schist, injected by granite, shown in plate 4. The central band here is one of those which appear as uniform, white bands in that view; here shown to consist of schist thoroughly and minutely broken up by, and inclosed in the granite.

Lower figure. Hand specimen of sheared, banded, acid gneiss from near the shore of Wellesley island, due west of Alexandria Bay. Shearing has produced numerous, slight faults, the shear planes are solidly welded up by secondary minerals, and dikes of the Picton granite cut across these, these of course not showing in the specimen. H. P. Cushing, photo

dack syenite. In the most basic variety seen, these dark minerals constitute no more than 15% of the rock, the remainder being feldspar with a little quartz.

Granting the equivalence of the rock with the general augite syenite, its age is rather definitely fixed as one of the great intrusives of the region, younger than the Grenville and the Laurentian granite, and also younger than the anorthosite intrusion. Since this latter rock is not represented in the district, and the only direct evidence of age seen in connection with the Theresa syenite is that it cuts the Grenville, this additional evidence is welcome.

Alexandria syenite. The intrusive mass of syenite called for convenience by the above name, since nearly the entire mass is in Alexandria township, lies west and north of Redwood, with a major axis of nearly 6 miles, and with a greatest breadth of nearly 2 miles; this on the supposition that but a single intrusion is here represented, as is believed to be the case. It is possible that two intrusions are here in which case the southern one fourth must be separated from the rest.

Much of the rock is considerably crushed, granulated and recrystallized, converting it into an augen gneiss. The size of the augen, many of which are a half inch long, bespeaks either a very coarse grained rock originally, or a porphyry, the latter being regarded as most probable. These coarse augen gneisses are chiefly peripheral, and mostly at the south end of the mass. Centrally, considerable cores of much less mashed rock remain which, while of medium coarseness of grain, do not approach the coarseness of the augen. The bulk of the rock is an augen gneiss with small augen, and it may be that the coarse augen gneiss at the south should be separated from the remainder; the two seem, however, to grade into one another, and no evidence that one cut the other was found, except that in a few localities the coarse augen gneiss is cut by dikes of fine grained red granite. These seem rather acid for dikes from the syenite. It is possible that they are stray dikes of Picton granite.

The least mashed cores show a rock of granitic texture and medium grain, composed chiefly of a reddish feldspar and black hornblende, the latter in sufficient quantity to give some of the rock a strong resemblance to a diorite. These least gneissoid portions always show much mashing, when seen in thin section, the feldspars being granulated at their margins, and the hornblendes fraying out into biotite scales. This change increases until

finally we get a rock in which but few unmashed feldspar centers remain, the hornblende has entirely disappeared, and the rock is a finely granular aggregate of feldspars, mica scales, and some quartz.

Of accessory minerals, apatite and titanite are prominent, the former being abundant for this mineral, and of good size, the latter usually rimming the magnetite, as well as occurring away from it. The feldspars comprise microcline, microperthite and plagioclase (oligoclase-andesine), with the latter somewhat in excess when the plagioclase in the microperthite is included with it. The quantity of the two, however, is not far from equal in most cases. There is little or no quartz in the least mashed rock, and the quantity steadily increases in the gneissoid varieties. Some of this increase is certainly due to reactions during recrystallization since quartz commences to appear with the appearance of biotite. On the other hand the rock varies somewhat in acidity and some of the quartz is unquestionably primary.

The coarse augen gneiss at the south has much the same mineralogy as the remainder, though more quartzose and acid, approaching a granite in composition. Smyth holds the view that it is a separate intrusion from the main mass of the syenite, and older, having noted an exposure in which the syenite appeared to cut the augen gneiss. We did not have the good fortune to observe any such exposure, hence his positive evidence must outweigh our lack of such. Chemically also the augen gneiss is much more acid than the syenite, being remarkably like the Picton granite in composition. If the two are separate, the augen gneiss is the older, and both are younger than the Laurentian, while the Picton holds inclusions of the augen gneiss.

This syenite differs considerably from the usual type of syenite of the Adirondack region, represented here by the Theresa syenite, both in general appearance and in mineralogy. Analyses and more detailed description will be given in a later section of this report. It is more gneissoid, giving the appearance of greater deformation than the Theresa syenite, and hence it is tentatively inferred that it is somewhat older than that. The appearance may however be entirely deceptive, since the one rock gives rise to abundant mica when deformed, and the other furnishes little or none, nor any other mineral which promotes foliation. Hence the same amount of deformation would produce a better foliated rock in the former case than in the latter, a rock which would appear more greatly deformed.

Picton granite. This is the latest, most extensive, most interesting, and most important of the intrusives of the region. It is named from Picton island (called Robbins island on the map) where it is most extensively quarried. It is, however, best and most extensively exposed on Grindstone island and would have been named after it except for the fact that the whole name was too long, and the term "Grindstone granite" possibly misleading. It is extensively exposed also on the west end of Wellesley island. Abundant dikes of it appear on the mainland of the Alexandria sheet, cutting the Alexandria granite gneiss and the Grenville schists, but the main mass falls short of reaching the shore. It does reach the mainland on the Clayton sheet, however, judging from the exposures of the Precambric inlier up French creek, and may have wide extent here under the Paleozoic rocks. Across the border in Canada it seems to have large extent, though it has not yet been differentiated from the Laurentian in mapping. If, however, we are correct in correlating the granite at Kingston with this rock, a bathylith of considerable extent is implied.

The general rock is a rather bright red granite of quite coarse grain. It varies much in this respect however, and much of the border rock is of much finer grain, as is also true of the general run of the dikes which radiate out from the mass. To a certain extent this diminution in apparent size of grain is due to mashing, but certainly the major part of it is a primary difference.

Red feldspars (microperthite, microcline and oligoclase) constitute 75% or more of the rock. Considerable quartz is usually present and is frequently characterized by a slightly bluish cast, which makes a helpful diagnostic feature of the rock. Hornblende and biotite are sufficiently abundant to show prominent black spots in the otherwise red rock. In the finer grained border varieties and dikes, these black minerals retreat, quartz becomes somewhat more prominent, and the rock appears more acid. The general rock, however, does not impress one as a particularly acid rock for a granite, and this impression is borne out on analysis (given in a later section).

The rock of the inlier to the south of Clayton, and that at Kingston are correlated with this granite with some reserve. The Kingston rock is a red granite of almost identical appearance with this, agrees closely in composition, and the only hesitancy felt in the matter is owing to the distance separating the two areas. In all likelihood the rock can be carried across on

the Canadian islands to the mainland and thence west to Kingston, but until this has been done some reserve must be felt in making the correlation. The rock near Clayton differs in containing no quartz, and in being somewhat more mashed than the generality of the rock. It is in fact an acid syenite rather than a granite. Otherwise the two are exceedingly alike, and since the granite itself is low in silica for a granite, approaching a syenite in that respect, but slight variation is needed to cause the disappearance of the quartz.

It must be borne in mind, in inspecting the maps, that the boundaries drawn between the Picton granite and the Laurentian are in the highest degree conventional. They are of the same vague sort as those between the Laurentian and Grenville, but even more vague than those because of the similarity of the two rocks. The fine grained dikes of the Picton are exceedingly like the acid dikes sent out from the Laurentian, and it is almost an impossible matter to tell which rock is in excess. On the other hand the maps do show the chief areas of the two rocks, bring out the fact that the one is younger than the other, and show their relative distribution and extent as accurately as possible in rocks of this kind.

That the rock is the youngest of the intrusives of the region is indicated in several ways. It shows less sign of mashing than do any of the others, that is its unmashed central core is relatively much larger. Besides its abundant inclusions of various Grenville rocks it contains also frequent masses of granite gneiss of Laurentian type, and sends abundant dikes into similar rock where bordered by it, as it is locally on both Wellesley and Grindstone islands; and also it contains inclusions of an augen gneiss which is absolutely identical in character with the rock of the Alexandria syenite. Such age for the rock then seems to us in the highest degree probable, though it falls somewhat short of actual demonstration.

Dikes of the granite are thought to range widely in the rocks east and south, though no attempt to indicate this upon the areal maps has been made. They are believed to be numerous present in the green schist belts of the western part of the Alexandria quadrangle, and also in the granite gneiss of that quadrangle. Even as far east as Alexandria Bay broad dikes of acid, usually fine grained, granite occur abundantly, cutting the granite gneiss all to pieces, and often inclosing sharp inclusions of it. We have never seen inclusions of this type held abun-

dantly in the aplite dikes of the granite gneiss itself, and regard the granite of the dikes as likely Picton.

The contact relations of this rock with those adjacent are of much interest. It was apparently richer in mineralizing fluids than any of the other intrusives, and gives rise to interesting contact rocks, to be described in the succeeding section. But the field relations are also most important and interesting.

While mapping Wellesley and Grindstone islands it quickly caught our attention that the abundant inclusions with which the Picton granite is everywhere charged were arranged in belts, that is, along a given line the inclusions were all quartzite, along an adjoining line they were all amphibolite, along another nothing but granite gneiss inclusions appeared. It was also seen that these belts had northeast-southwest trend, concordant with the general rock strike of the region, and that further the individual inclusions to large extent retained their original orientation and dip, notwithstanding the intrusion. Our strikes and dips, read on the rocks in the field, gave absolutely concordant results as we passed from one inclusion to another, results also concordant with the readings obtained on the same rocks beyond the reach of the intrusion. We were able to map the original belts of Grenville quartzite and schist, and the intrusions of Laurentian granite gneiss, as accurately as though the Picton granite was not present, so little had they been disturbed by the intrusion. An attempt has been made to bring out these facts upon the geologic maps. We could only account for the phenomena on the assumption that we have exposed here the very roof of this portion of the batholith, the abundant inclusions representing masses but just loosened from their original place, not greatly sunken, and preserving unimpaired their original orientation. If this be the correct interpretation, the locality furnishes a fine illustration of the general phenomenon.

Other intrusions. While the above furnish the only examples of intrusions of considerable size in the region, there are many others of small size, mostly too small to map, and which it seems hardly worth while to describe in detail. These are chiefly of granite gneiss, and are regarded for the most part as of Laurentian age, and as representing comparatively small upward protrusions from the general roof of the great mass of Laurentian granite gneiss which is believed to underlie the entire district, except where broken through by the later intrusions. A good

illustration is that of the granite gneiss in the extreme southeast corner of the Alexandria sheet, which forms a wonderful cliff along the Indian river.

In quite a number of localities syenitic rocks were found, always of trifling extent, and with field relations wholly indeterminate.

At the west end of the upper bridge at Theresa, is a small intrusion of gabbro, which is but little mashed, and has some features of interest in that it recalls the anorthosites and gabbros of the general Adirondack region, and is the only representative of these rocks seen here. It is a dark colored rock, showing numerous, glittering, lath-shaped feldspars up to an inch in length, on broken surfaces. It is made up of feldspar (labradorite), augite, hypersthene and hornblende, with considerable magnetite, and a little pyrite and apatite as accessories. The feldspar constitutes from 60 to 70% of the rock. In composition therefore it is distinctly a gabbro, though with more abundant feldspar than the usual Adirondack gabbro. Yet, in spite of the coarsely lath-shaped feldspars the structure is more nearly that of a gabbro than a hyperite, recalling in this respect the anorthosite-gabbros farther east.

Diabase. Cutting all the other Precambrian rocks of the region, occasional dikes of trap rock are found. The fact that they cut all the other rocks shows that they are younger, but it can also be shown that they are much younger than the other igneous rocks, though nevertheless older than the Potsdam sandstone. They are found only in the form of dikes, which are lava-filled fissures that in general represent plugged channels of ascent of the molten rock, leading downward to some source of supply of the material, and tending upward toward the surface. The dikes have chilled borders, showing that the inclosing rocks were comparatively cool and hence at no great depth beneath the surface at the time of solidification. Furthermore they show no sign of having undergone the kind of deformation which all the other igneous rocks have experienced in greater or less degree, a kind which takes place only at considerable depths. Since the diabases cooled much nearer the surface than the granites and syenites, a long time interval of surface erosion during which a considerable rock thickness was worn away from the surface. must separate the two.

In the district mapped these dikes have a somewhat unequal distribution. They are most abundant on Grindstone island, seven having been noted there, mostly of large size, none of them less than 20 feet wide, and ranging from that up to 100 feet in the case

of the dike numbered 1 on the map. Two have been found on Wellesley island, the wider of which measures 30 feet. Seven have been found on the mainland of the Alexandria sheet, in rather widely scattered distribution, and in general much narrower. None have been observed on the Theresa sheet. Smyth has described them as abundant on the Canadian mainland and islands in the vicinity of Gananoque, hence in the near vicinity of Grindstone island, which would seem to have been the chief center of activity. For petrographic details the reader is referred to his account which, though based on Canadian material, also describes these accurately.¹

The dikes trend in various directions, from northwest around through north to northeast. Smyth states that those seen around Gananoque trend chiefly to the north, and were all cutting granite. It is to be noted that all those trending northeast, in our district here, are cutting Grenville rocks with general northeast strike, while all the dikes cutting the igneous rocks trend north or northwest. This is also true of two of the dikes cutting the Grenville, but in both cases the Grenville is in comparatively small bulk, and entirely inclosed by igneous rocks. The dike directions are therefore apparently determined by preexisting structures in the rocks, by the strike in the Grenville, and by a joint set in the igneous rocks. Small masses of Grenville rocks did not suffice to change the direction of dikes passing across them, the igneous rocks here being the determining factor.

Though they give no evidence of having been severely deformed, yet the rock of the larger dikes does show evidences of considerable pressure. Many of the feldspar crystals are distinctly bent, and both the feldspar and augite of the rock shows evidence of strain by their undulatory extinction. In this respect they contrast with the diabases of the eastern Adirondacks, which show no such strain effects. The eastern dikes also have chiefly east-west trends, differ somewhat in mineralogy, and are more numerous and widespread; and are also separated from this area by a wide region in which such dikes are absent. We seem here therefore to be dealing with a wholly different center of igneous activity, and a much less extensive one than that farther east.

Owing to their size and comparative freshness these dikes have a potential value in the region as a comparatively accessible source of good road metal.

Contact rocks. The contact effects of the igneous rocks upon the Grenville sediments, and vice versa, may be grouped under three

¹ N. Y. Acad. Sci. Trans. 13:209-14.

categories, effects produced upon the igneous rocks themselves, effects of the igneous rocks upon the sediments whereby rocks of intermediate composition are produced, and effects produced upon the sediments by the injection into them of fluids from the igneous rocks, fluids rich in mineralizing agents, and of quite different composition from the general mass of the igneous rock.

Bleaching of granite by limestone. In the early stages of the work it was noted that, while granite dikes and knobs of all sizes were of frequent occurrence, cutting the Grenville limestone wherever exposed, in all cases the granite was white, nearly as white as the limestone in fact. The granite of the bathyliths is, however, uniformly of red color, as are also the dikes in rock other than limestone. This led to search for limestone contacts along the margin of the Antwerp bathylith and of the smaller granite intrusions of the Theresa sheet, when it was found that in every case the margin of the granite, adjacent to the limestone, was turned white. It also proved to be the case in subsequent work that whenever, in passing over granite country, a whitening of the rock was observable, directly beyond crystalline limestone was sure to be found. It also was found that the general granite of the Antwerp bathylith had had singularly little contact effect upon the limestone, pure, unchanged limestone lying directly in contact with the granite in most cases, and that the dikes also had had no contact effects, so that the rather unusual condition was presented of granite-limestone contacts in which the granite was the rock showing contact effects, not the limestone.

Study of the white granite, both chemically and in thin section, affords no explanation of the change. The white granite is in general somewhat more acid than the red, but that is believed to be nothing more than an expression of the general fact that the dikes which radiate out from the bathyliths are more acid than the main mass, whether they be red or white (they are usually red in all rocks except the limestone), and that the granite also is apt to become more acid near the margins. A little tourmalin is sometimes developed in the granite where white, but it also developed elsewhere. The change seems to consist merely in a decoloration of the feldspar, changing it from red to white; that of course on the assumption that the red color of the feldspar is original and not a later coloring due to slight alteration. In that case, however, it is difficult to understand why both feldspars, of the white granite as well as of the red, should not have undergone the alteration; this seems in fact so highly improbable, that we seem justified in regard-

ing the color as beyond question original. The red color which so many feldspars possess is usually ascribed to ferric oxid, though in general without any definite proof in the matter. In such case the loss of color might be ascribed to simple reduction of the iron, but what reducing agent the limestone might furnish is a difficult problem and greenish, rather than white, feldspar would likely result. Analyses of both white and red granites are given on a later page, where the matter will be somewhat further discussed. The chemical differences between the two rocks are but slight, and we are in doubt whether in any recognizable respect they are due to influence of the limestone. The field relations are, however, perfectly clear, and susceptible of no other explanation.

Mixed rocks. Rocks which seem definitely of intermediate composition between the intrusive and a sediment, to be due to the intimate penetration and final digestion of the latter by the former, and which show all stages in the process, occur as the result of action of granite upon amphibolite and upon quartzite. In the former the action is chiefly seen in the case of the amphibolite inclusions which so abound in the granite gneiss, and which are found in all stages of being first penetrated by films of the granite and later slowly absorbed by it. The process has already been described; so has the gradation of granite into quartzite which is found in some localities and which seems only explainable on the assumption of production of a border zone of true mixed rock between the two.

Contact rocks. These, as here understood, result from the injection into the sediment of fluids from the igneous rock which contain only certain of its constituents instead of all, and which may, and often do, differ very materially in composition from the rock itself. The injection is apt to be more or less local, here much, there little, or none at all; the injected fluid may differ in composition at different points along the border of the igneous mass; the bordering rocks themselves differ from place to place, and finally the various igneous masses are quite sure to differ among themselves in the character of their mineralizing fluids. Since we have here three separate granite bathyliths, to say nothing of the syenites and smaller granite masses, and Grenville rocks of great variety of composition, the opportunity for contact action of diverse sorts is exceedingly good.

Green schists in Alexandria. Reference to the geologic map of the Alexandria quadrangle will show, to the south and southwest of Alexandria Bay, three northeast-southwest ridges of Grenville schists. These are cut out on the north by the granite of the

Alexandria bathylith, though there is a zone between the two in which exposures are poor and infrequent. They are separated from one another in part by tongues of Potsdam sandstone, and in part by low, marshy valleys in which no rock outcrops appear. The exposures, however, cover an area of several square miles, and extend to a distance of at least 3 miles from the edge of the bathylith. The schists are everywhere cut by dikes of granite, most numerous as the granite is approached. While chiefly of the Alexandria granite gneiss, it seems to us that dikes of the Picton granite are also present numerously, though it is difficult to arrive at certainty in the matter. Certainly they are present in the granite gneiss itself. Nowhere else in northern New York have we seen just this type of schists, except as occasional occurrences of small extent and bulk. We are disposed to regard them as contact rocks, produced by the action of the granite upon what were, prior to the intrusion, somewhat impure limestones. We are disposed also to regard the Picton granite dikes as especially influential in the action. It must be frankly stated, however, that there are certain difficulties in the way of this view, and they will be later summed up.

The schists are well banded and foliated and range from light to dark green, or greenish black, in color. They are usually of finely granular texture though these alternate with somewhat coarser grained bands. These latter show poorer foliation and are mottled green and pink in color. Narrow, dark red bands sometimes appear, due to subsequent infiltration of ferric oxid. At times the green minerals become scant, and the rock then has a light red to pink shade. Narrow bands of black amphibolite and of finely micaceous schist also appear, and an occasional thin quartzite band. But the bulk of the series is of green schist. Granite dikes and dikelets abound everywhere, cutting across or parallel with the bedding, in the latter case often forming a good injection gneiss. The dikes are of fine, granite gneiss, of coarse granite, of yet coarser granite pegmatite, or of quartz, the first most abundant.

In composition these green schists are essentially feldspar-pyroxene rocks, the latter of green color and responsible for the general hue of the rock. Actinolite is commonly present, and very abundant in some of the bands; it is the only amphibole noted in the schists, except in the occasional amphibolite bands. Epidote is often present, though far less common than the actinolite. Some layers hold frequent, small, light colored garnets. Small, scattered, black tourmalins occur throughout the rock in all exposures.

Small titanites *abound* in the rock, magnetite and hematite appear in varying quantity, with pyrite, apatite and zircon as other accessories.

Quartz is present in many of the bands but seldom in any great quantity and often wholly absent. The feldspar is in part microcline and in part plagioclase (andesine-labradorite); some microperthite is usually found also, and often much feldspar not characteristically marked.

In addition to the above minerals the rock nearly always contains calcite, and this in steadily increasing quantity as the distance from the granite batholith increases. The rocks from the schist inlier in the Potsdam due east from Omar, average 20 to 25% of calcite; in the long ridge just to the north of this it occurs in large, though somewhat less amount; while in the ridge northwest of this, and nearest the granite, much of the rock shows but little calcite, only the coarser, mottled beds having it in quantity. The calcite is coarsely crystalline, in sharply bounded individuals, and clearly formed at the same time as the other constituents of the rock.

The mineralogy of the schists strongly suggests contact effects, the tourmalin, actinolite and epidote being especially suggestive in this respect, none of them being normal Grenville minerals, away from the immediate vicinity of igneous rocks. The green pyroxene also is an abundantly formed contact mineral in the Grenville, though not so distinctive of contact metamorphism as the others. These, with the constant presence of calcite, give an impression that we are here dealing with a limestone belt much changed by contact action, with the granite and pegmatite dikes which abundantly penetrate the series as the source of the mineralizing fluids. The fact that these green schists, though here present in great bulk, are not a usual member of the Grenville succession in the general region, also suggests a local cause for their presence. It would seem that a series so thick could not but occur repeatedly elsewhere were it an ordinary member of the general series. Similar rocks do occur in small bulk in the general schist series north of Millsite lake, but their small amount here but emphasizes the bulk of the other occurrence.

As opposed to this suggestion of contact origin, the breadth of the belt and the distance it extends from the granite margin, its general uniformity of character, whether in contact with a dike or at a considerable distance from one, whether near the granite margin or remote from it, (the only observed difference

being in the amount of calcite, and that a very slow and gradual change), seem more suggestive of regional than of contact metamorphism. On this view the belt would consist of original impure limestones and calcareous shales, metamorphosed to the pyroxene-feldspar-calcite combination, and with the tourmalin, actinolite and epidote alone due to the later contact action. While unable to definitely decide between the two, the first seems to us the more probable. It is possible that the granite is close in place underneath the whole belt. In our view, then, the belt is due to the contact action of an especial granite, its localization being thus explained, acting upon a limestone series of considerable thickness, and certainly somewhat impure at least, as shown by the bands of quartzite, amphibolite and mica gneiss within it. Part of the regular Grenville succession of the area consists of alternating thin beds of limestone, various schists and an occasional quartzite, and it would seem as if such a combination might well be turned over into a group like that of the green schists by contact metamorphism. This would be all the more likely if acted upon by two successive, granite injections as is supposed to be the case here, since dikes of Picton granite are believed to be present.

The coarse pegmatite dikes of the north schist ridge, which furnish well crystallized specimens of orthoclase and specular hematite, to be found in many mineral collections, have already been described by Smyth.¹

Tourmalin contact zones in Alexandria. The Picton granite is found cutting Grenville quartzite and amphibolite, but no other members of the series, and the same is true of its *known* dikes; that dikes suspected to belong to it cut other members has just been seen. This granite seems to have been much more potent in tourmalin-forming capacity than any other granite of the region and its contacts with the Grenville on Grindstone and Wellesley islands are characterized by narrow tourmalinized zones which Smyth has clearly described, as follows:

Along their margins these dikes frequently show much black tourmalin and this is usually most abundant in the very narrow ones, in which the imperfect crystals of tourmalin interlock across the entire width. At the same time the schists along the contact become impregnated with fine, granular tourmalin, producing strips and irregular areas of a lustrous black rock. The remarkable feature about these contact zones in the schist is their extreme irregularity in form and extent, and their entire independence of the magnitude of the accompanying dike. A dike of granite a foot wide

¹ *op cit.* p. r94.

may have no contact zone, while a mere thread of granite a few feet distant, may be bounded on each side by a band of the tourmalin rock 2 or 3 inches wide. Again, the tourmalin, instead of forming a continuous band, appears in lumps and bunches of every conceivable shape, irregularly scattered along a dike, and sometimes extending several inches away, at right angles to the course of the dike.¹

Tourmalin is also at times developed in the quartzite as well as the schists, but not in the same definite manner. It is not at all certain that dikes from the Alexandria bathylith are excluded from the category of rocks producing this contact effect. In many cases the dikes from the two bathyliths can by no possibility be distinguished from one another. In addition to these bands and bunches of abundant tourmalin, developed in this localized fashion, more scattered crystals of tourmalin, of the same evident origin, range much more widely through the rocks.

Smyth dissents from the view that the Picton granite was especially influential in the formation of these tourmalin zones, and in other contact phenomena. He points out that, in his belief, the tourmalin zones are most abundant at the extreme east end of Wellesley island, quite remote from the Picton granite, though with the Alexandria bathylith near at hand; also that the Alexandria bathylith is much nearer the Alexandria green schists than the Picton. He therefore regards the Alexandria bathylith as the most important granite of the region in producing contact effects. We are not sufficiently certain of the truth of the opposite view to urge it, and simply chronicle the matter as one on which we mildly disagree. It is not a matter of great importance in the interpretation of the geology of the region, on the general features of which we are in absolute agreement.

Contact amphibolites. Adams has recently shown conclusively that, in central Ontario, amphibolite occurs as a result of intense contact alteration of Grenville limestone by granite, limestones passing into rocks in which pyroxene, hornblende, feldspars and scapolite appear in increasing quantity up to final disappearance of calcite, and with final entire replacement of pyroxene by hornblende and scapolite by feldspar.² We have had the privilege of going over his territory with him, and fully agree in his conclusions. Perhaps the chief interest attaching to his work is the explanation thereby afforded of the abundance of inclusions of amphibolite in the Laurentian granite gneisses, where cutting the Grenville rocks,

¹ *op cit.* p. 190.

² Adams, F. D. Jour. Geol. 17:7-18.

the scarcity of inclusions of other types, and the invariable utter absence of limestone inclusions, notwithstanding the abundance of limestone in the formation. Beyond doubt many of these inclusions represent limestone fragments altered in this fashion. Intense alteration, however, seems necessary, and that perhaps furnishes a reason why the comparatively small fragments caught up in the granite mass are so uniformly changed over, while at the contacts the change is much less obvious, or common. In our district here we have amphibolite inclusions everywhere in the granite gneisses, but no instances of the conversion of pure limestone into amphibolite along the contacts, similar to those in Ontario. There are, however, one or two instances of similar alteration on a small scale, in connection with narrow bands of limestone and small granite intrusions. The most clearly shown of these is right in the village of Theresa, at the road metal quarry near the lower bridge. The rock quarried here is a contact phase of the limestone cut through and through by granite dikes. The chief rock is green in color and consists of pyroxene, titanite, feldspars and calcite, the latter running as high as 50% of the whole in the portions of the rock most remote from the dikes. In contact with these, however, the rock is black, consists chiefly of hornblende and feldspars, though with a little remaining pyroxene and calcite, and has nearly completed its transformation into amphibolite. Very near at hand is the pure limestone band shown in plate 2, and there can be little question but that the green rock of the quarry is an altered phase of that, and no question at all but that the green rock is changed into amphibolite by the granite. On a small scale then it is a change identical with that described by Adams.

Contact rocks of the Antwerp bathylith. In so far at least as the portion of the Antwerp bathylith included within the mapped district is concerned, the contact action of this granite is but slight, and it would seem to have been quite deficient in mineralizing agents, though as effective in the production of mixed rocks as the other granites. The dikes and stocks of white granite run everywhere through the limestones without affecting them any, except in trifling amount in a few localities, nor does near approach to the margins of the bathylith produce any observable change in the Grenville rocks. In the case of dikes of granite pegmatite however, some contact action is the rule, coarsely micaceous rocks being the usual ones produced. Locally the mica becomes very coarse and in well formed crystals, so much so that at one locality north of Theresa an attempt was made to mine it commercially. The mica

is of light brown color, in the coarser varieties very light brown, resembling muscovite, though it seems undoubted phlogopite.¹ Scapolite is also an abundant mineral in these zones, a phlogopite-scapolite-calcite rock being the usual combination. This is not one of the customary types of Grenville contact rocks in the general region, though the common one here.

There are two other types of contact rocks which occur in small quantity within the area here, though common enough elsewhere, which call for brief attention. They occur in the district east of Redwood where Grenville rocks of all types are cut by small granite masses. One is a heavy, basic, black rock, weathering rapidly, and composed chiefly of green pyroxene and black hornblende, with a little graphite, considerable pyrite, and some 15% of calcite remaining. Heavy, pyroxenic rocks of this type occur throughout the Adirondack region at limestone contacts, though usually not so hornblendic as this rock.

The other rock consists of large, gray green pyroxenes set in a felt of tremolite needles, with rather abundant pyrite as the only accessory mineral. Such tremolite rocks occur not infrequently in the Grenville, the tremolite quite commonly altering to talc. The especial interest attaching to this particular exposure is that the tremolite rock is developed at the contact of granite against Grenville rusty gneiss, and seems quite certainly a result of the contact action of the one upon the other. So far as we recall, just that type of contact action has not heretofore been noted in the region.

Great Precambrian erosion

The Grenville rocks are the only Precambrian sediments in the region, and are of very early Precambrian age. The remaining rocks of this age in the district are all igneous, and there is no evidence that any later Precambrian sediments were ever deposited hereabouts, though it is possible that some such were deposited and subsequently worn away. The Precambrian rocks of the present surface, both sedimentary and igneous, present characters which, so far as we know, are only given to rocks under conditions of high pressure, and at least moderately high temperature, conditions which in general prevail only at considerable depths below the surface. All the igneous rocks except the diabases give evidence that they solidified well beneath the surface, and the deformation of both these and the sediments is of deep-seated type. It is, however, not

¹ It is of the second order and with very small axial angle.

quite so prominently of this type as in the case of the corresponding rocks of the central and eastern Adirondacks. We are forced to argue that, when these rocks were deformed, a considerable thickness of other rock overlay them, which thickness was subsequently worn away. This surface wear goes on very slowly at best, and must have been continued through long ages, yet was completed before Potsdam deposition began. The time involved is many millions of years, in all probability a rock thickness of at least a mile or two was removed, and yet at the close the region was pared down to a surface of comparative smoothness. Much Grenville has thus disappeared, the tops of the igneous bathyliths are gone, together with whatever of younger rocks may have been present above them. The diabases were intruded toward the close of this long period, since plainly they solidified not far beneath the surface.

PALEOZOIC ROCKS¹

The Paleozoic rocks of the district, for mapping purposes on maps of this scale, are separable into six quite distinct lithologic units, which in large part coincide with the subdivisions of these rocks made long ago by the early geologists of the State. These are, in order of age from below upwards, the Potsdam sandstone, Theresa dolomite, Pamela limestone, and Lowville, Black River and Trenton limestones. Above the last named the Utica and Lorraine shales come in, but these nowhere reach the map limits, their northerly boundaries being found on the Watertown and Sacketts Harbor sheets, next south.

The basal member of this sedimentary series, the Potsdam sandstone, was deposited upon the worn surface of the Precambrian rocks, and in order to properly describe the sandstone it is necessary to present in some detail the character of this surface.

Precambrian surface underneath the Potsdam

That the surface on which the Potsdam sandstone was laid down was far from being an even one was clearly stated by Smyth, in his report on the district.²

That a similar irregular floor is present in many parts of Canada, of the upper lake region and of northern New York, has been shown by many observers. There is therefore nothing novel in the features to be described, but they are worthy of somewhat extended descrip-

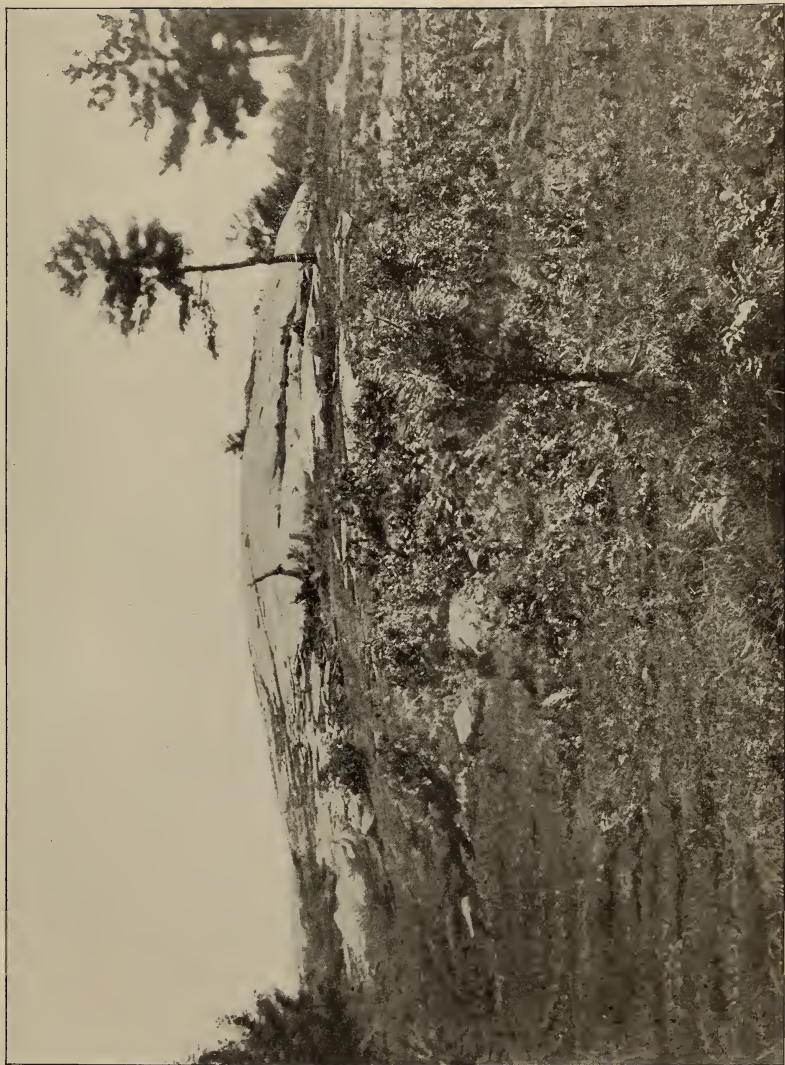
¹ By H. P. Cushing.

² N. Y. State Geol. 19th An. Rep't, p. 1100-1.



The "granite knob" country. View taken from nearly 3 miles southeast of Theresa, looking southeast, showing one large and several small knobs of the Antwerp granite batholith. H. P. Cushing, photo, 1907

Plate 7



A granite boss, Forsters landing, 3 miles east of south of Chippewa Bay, Alexandria quadrangle. H. P. Cushing, photo, 1908

tion since it is very exceptional to have the evidence as abundant and as clearly shown as it is here.

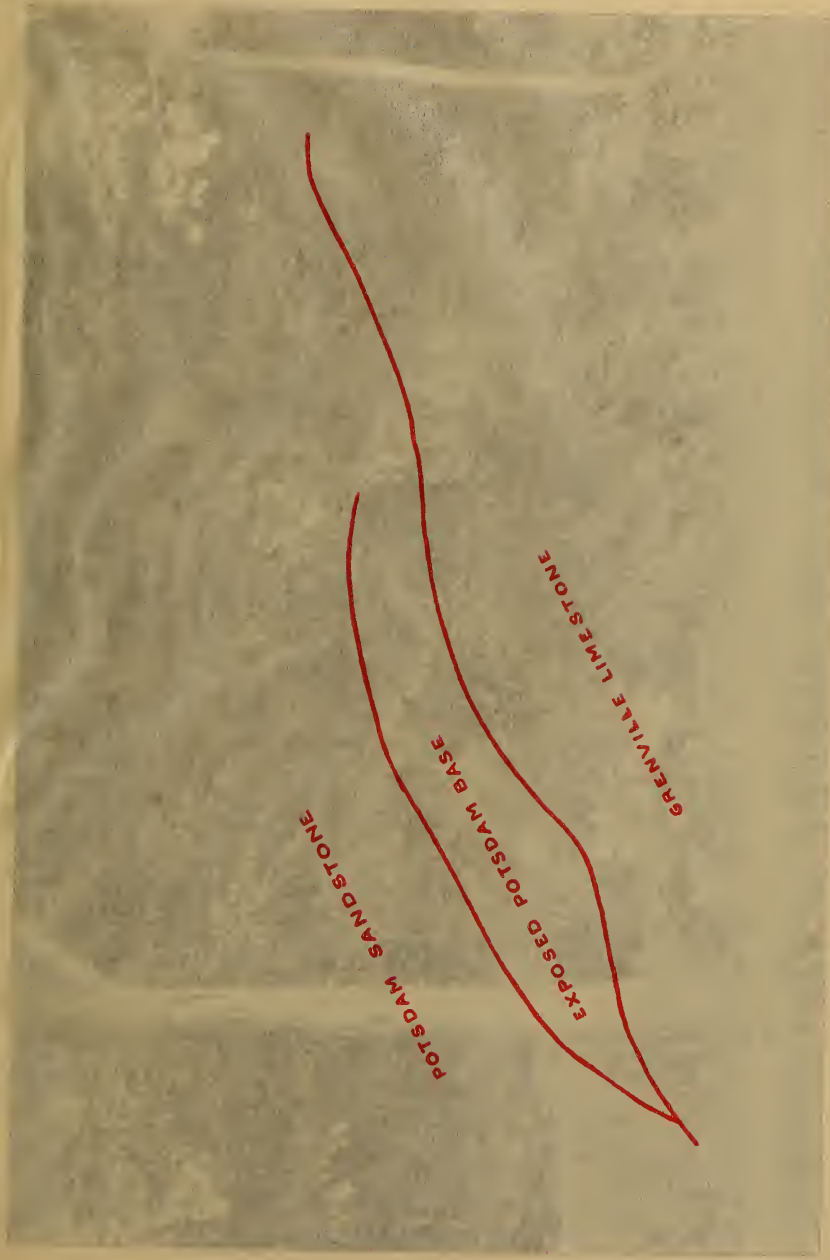
The evidence of surface irregularity is of threefold nature, (*a*) that given by exposures of direct contacts, (*b*) that given by the tracing of the lines of contact of the Potsdam and Precambric, even without exposures of the actual contact, and (*c*) that given by the topography of the present Precambric surfaces, since it can be shown that these surfaces are substantially those upon which the Potsdam was originally deposited; in other words that the Potsdam is just being pared away from the Precambric over part of the district, its numerous outliers testifying to its former presence over the whole and to the recency of its removal where now absent.

Where the Potsdam has been removed the Precambric surface disclosed is one of low ridges and valleys, with general northeast-southwest trend. The ridges are low and with hummocky surface, and the valleys are broad and shallow, and developed on the weak rocks (such as the limestones and weak schists) or on lines of structural weakness (as along lines of sheared and shattered granite). The extreme of relief does not much exceed 100 feet, and is generally less. The quartzites, resistant gneisses and some long and wide granite dikes constitute the ridges. In the relatively elevated country occupied by the igneous batholiths the surface is of the knob and basin type [pl. 6 and 7]. The numerous granite dikes and small bosses which cut the limestone and are resistant to weathering, diversify the valley bottoms. Hence a large part of the area consists of slopes, and extensive flats do not appear.

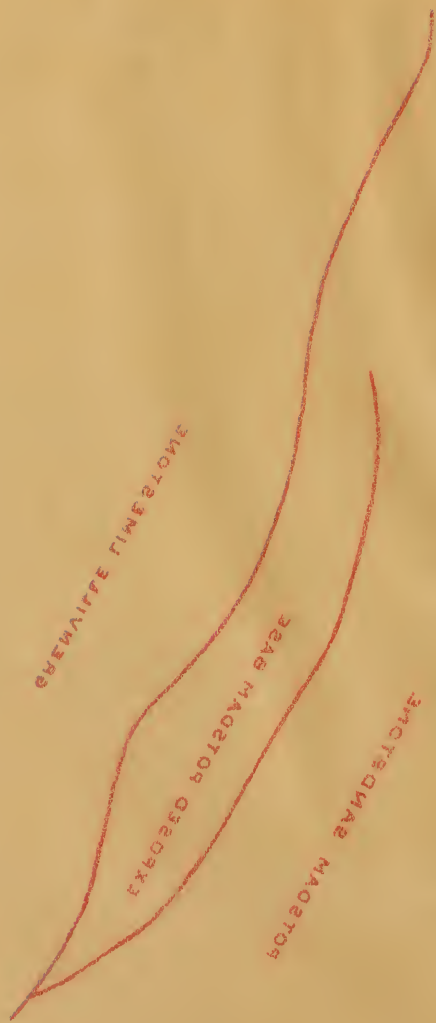
The surface underneath the Potsdam is precisely of this sort. The smaller Potsdam outliers are usually mere remnants remaining in places where the floor was lowest and the sandstone thickest. The larger outliers cover both high and low ground. The Potsdam resists wear, and hence usually presents cliff fronts at its margins, showing thicknesses of from 20 to more than 60 feet of sandstone, yet even with these thicknesses the summits of the outliers are often overtopped by neighboring granite knobs. The evidence of the occasional inliers of Precambric rocks in the Potsdam is even more obvious. The two small inliers east of Goose bay (Alexandria quadrangle) along the road from Alexandria Bay to Chipewa Bay, have their tops at the same level as that of the sandstone plain in which they lie, yet a 20 foot thickness of sandstone shows at the Potsdam margin, just to the northward. This line of evidence might be pursued at great length but since it is less conclusive than are the other lines the above will suffice.

The second line of evidence is that obtained in following and mapping the long Potsdam boundaries. A single example, that of the Potsdam margin along the west bank of Indian river in the southeast corner of the Alexandria sheet and for 1 mile southward on the Theresa sheet, will serve as well as a multitude of illustrations to indicate what the evidence is. The section is convenient since it has a horizontal base, the edge of the Indian river marsh. The Potsdam faces the river in a prominent bluff which, when it comes down to the marsh level, as it frequently does, forces the pedestrian to take to the swamp, so that the walk is not recommended as a pastime. But the unbroken cliff margin renders accurate mapping of the Potsdam base possible, and underneath it Precambrian exposures are numerous. At the south end of this section, on the Theresa sheet, inspection of the map will show the Potsdam coming down to the river level in a point. Going northward it soon runs up the bank until the base is 40 feet above the river, with Grenville limestone outcrops showing beneath, then it returns to the river level and again rises, repeating the performance three times within a mile of distance. Soon after passing on to the Alexandria sheet the sandstone retreats prominently up the bank and back from the river, showing a 60 foot thickness of limestone underneath, then returns to marsh level, withdraws 30 feet up the bank, comes back again forming a point, retreats quickly for 60 feet up the bank and again returns to the river, all the while with limestone underneath, cut by occasional granite dikes, so that all these oscillations merely represent irregularities of the limestone surface. Northward from this last point of reaching the river, however, the limestone is cut out by granite gneiss, and this turns the Potsdam straight up the bank and out to the road, with a rise of more than 100 feet in the level of the Precambrian surface. Equally striking are the oscillations in level of the same margin when followed southward on the Theresa sheet, and this margin is easy to follow, using the railroad as a base. There are many other excellent examples, since this sort of thing is the rule throughout the district. The mapping of the Potsdam base is thereby rendered laborious but nothing can be imagined more beautifully demonstrative of the character of the surface on which the Potsdam rests and its identity with that of the surface from which the Potsdam has been removed.

Lastly there is the evidence given by the actual contacts. There are quite a number of these, more than the writer has seen in the entire remaining border of the Adirondack region. Besides the actual contacts there are a host of others where but a few feet of



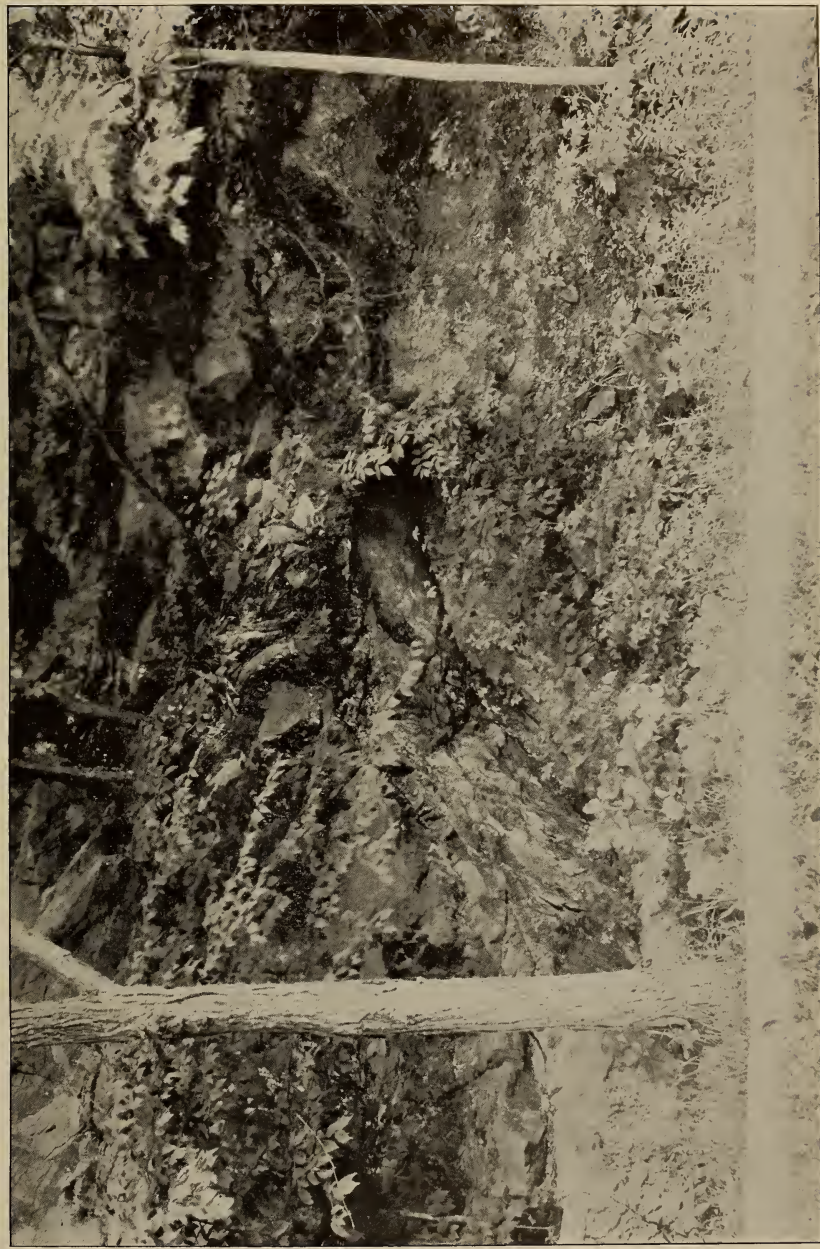
Geological cross-section showing the relationship between the Potsdam Sandstone, the Exposed Potsdam Base, and the Grenville Limestone. The Potsdam was deposited on the Grenville Limestone, and the Exposed Potsdam Base was deposited on the Potsdam Sandstone. The Grenville Limestone is a crystalline limestone, and the Potsdam Sandstone is a quartzite. The Exposed Potsdam Base is a quartzite, and the Grenville Limestone is a crystalline limestone.



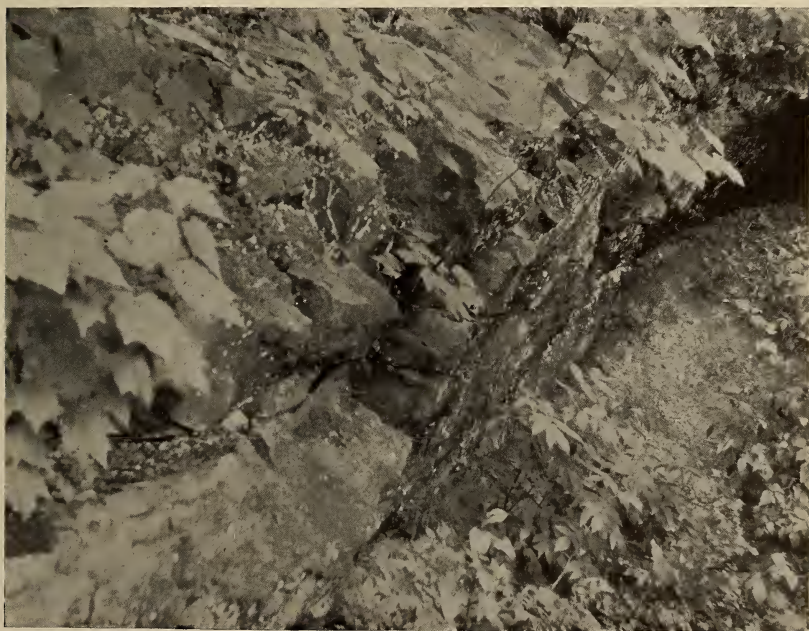
GREENAIFE LIMESTONE

EXPOSED POTSDAM BASE

POTSDAM SYNCLINE



Contact of Potsdam sandstone on Grenville limestone in Theresa village near the upper bridge. The Potsdam was deposited on a steeply sloping limestone hillside, and the limestone has now been somewhat eaten away leaving a portion of the actual under surface of the sandstone exposed. This is sparingly charged with pebbles. H. P. Cushing, photo, 1907



Upper view. Contact of Potsdam sandstone on Grenville limestone just north of lower bridge at Theresa, near the point at which plate 11 was taken. The Potsdam base rests against the side of a limestone hill, and the boy is seated on the limestone, with his hand resting on a portion of the Potsdam base from which the limestone has been removed.

Lower view. Nearer view of a portion of plate 9 showing the rotted limestone and the portion of the Potsdam base which projects out beyond it owing to removal of the limestone. H. N. Eaton, photo, 1908

Plate 8



Contact of the Potsdam sandstone on Grenville quartzite by roadside 1 mile southeast of Redwood, looking west. The quartzite is somewhat contorted but its dips are not steep, from $20-30^{\circ}$. The upper view is from 15 feet distance, the lower with the camera only 4 feet away and showing only the lower layer of the Potsdam clearly. H. N. Eaton, photo, 1908

space intervenes. This is due in part to the many miles of Potsdam boundary in the region and in part to the scanty glacial deposit and hence abundant rock exposures. Many of the exposed contacts are on slopes, and on limestone, and it is these that are most unusual and interesting.

Plate 8 shows Mr Eaton's photographs of a contact on quartz schists, 1 mile southeast of Redwood on the Rossie road, a contact already described and figured by Smyth. The contact here is on the summit of a ridge of quartzite, hence is fairly horizontal where photographed, though the level drops away on each side at no great distance.

Two fine examples of contacts on slopes occur within the limits of the village of Theresa, along with others almost as good. One of these is by the roadside a short distance west of the upper bridge. A high Potsdam cliff borders the roadway for a few rods, with the base of the formation well below the road level. At the west end the base comes up to the road level, the cliff sets back some 20 feet, and the base rises sharply to from 12 to 15 feet above the roadway, exposing impure Grenville limestone underneath. The recess faces north, and is beset with shade of trees so that satisfactory photography is difficult, the view shown in plates 9, 10 being unsatisfactory. The surface of deposit has an angle of slope of 45° or more, and the soluble limestone has been somewhat eaten away from beneath the sandstone, so that several square yards of the actual basal surface are exposed. This is set with occasional quartz pebbles, but these are sparse, and except for them the rock is quite like that above. The sandstone is very massive and irregularly bedded, with a semblance of parallelism to the floor of deposit as is usual with the basal Potsdam hereabout.

The other contact mentioned is exposed on the north side of the river just above the lower bridge. The map shows a small Potsdam outlier there, whose narrow, southwest edge appears as a low cliff by the roadside [pl. 11]. The ground level falls toward the river and at the south end of the cliff the base of the sandstone is exposed, resting on Grenville limestone underneath. Plate 10 is a photograph of this contact. At the south the cliff bears sharply away from the road and by turning into the yard of the first house to the south a fine exposure of the south margin of the outlier is obtained, showing the Grenville limestone rapidly rising in altitude and carrying up the Potsdam base with it. The limestone surface falls not only to the west but also to the north. As in the previous case a part

of the sandstone base is exposed, owing to solution of the limestone beneath. A sketch of the relations here is given in figure 1, the

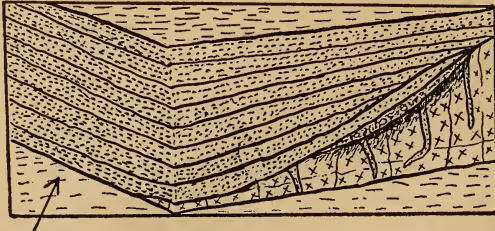


Fig. 1 Potsdam contact on Grenville limestone, just north of lower bridge at Theresa, showing the sloping Grenville hillside on which deposition took place, and the sand-filled cracks in the limestone.

arrow showing the camera position for plate 11. It is at this locality that the best examples of sand extending down into widened joint cracks in the Grenville limestone were seen. At the east end of the outlier the limestone is cut out by granite gneiss, whose summit is 20 feet above the top of the sandstone, hence terminating the outlier in that direction. Of course the full original thickness of the sandstone is not present in the outlier, but only the mere basal portion, and formerly the sandstone extended over the granite as well.

Another interesting contact occurs along the Potsdam front, $2\frac{1}{2}$ miles northeast of Theresa. From a previous northeasterly trend the front here turns and for a mile and more runs northwest across the strike, crossing a prominent granite ridge and then dropping 70 feet in level into a limestone valley. Near the turn the contact sketched in figure 2 is shown. A low knob of ferruginous, quartz schist projects upward into the Potsdam to the amount of 20 feet.

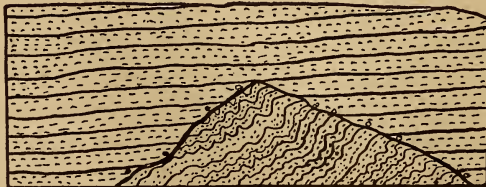


Fig. 2 Potsdam contact on Grenville quartz schist, $2\frac{1}{2}$ miles northeast of Theresa. The much contorted and steeply dipping schists constitute a ridge over 20 feet high around which the Potsdam was deposited.

The Potsdam here is more evenly bedded than in the cases described at Theresa, the bedding abutting squarely against the sides of the knob. Its small size as compared with the long ridge slopes of the other contacts is thought to be the chief reason for this difference.

There is an occasional quartzite pebble along the contact, otherwise the sandstone is normal, and gives no sign of basal conditions.

Around to the left the slope of the knob steepens. There are occasional bands of coarsely crystalline, purer quartzite in the schists which are far more resistant to weathering. On this steep front one such layer projects as a cornice with the sand-filling beneath, as shown in figure 3. Photographic attempts here proved wholly unsatisfactory.

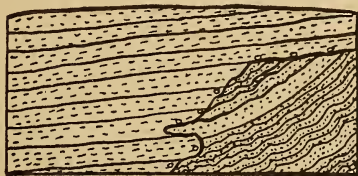


Fig. 3 A nearer view of a portion of the contact showing a local steep slope of the hill and projecting cornice of an extra-resistant quartzite layer.

Besides the contacts on larger slopes, of which the preceding are instances, there are a number of minor examples of the sort, chiefly as filled hollows of the limestone surfaces. A sand-filled hollow of the sort appears at the top of the limestone quarry near the Theresa boat landing, and is shown in plate 2. In the section there shown the hollow is about 6 feet deep and with twice that width at the top. Another example may be seen at the quarry just south of the Theresa depot, though the overlying sandstone is gone except for the small residual patch resting in the hollow so that its original size can only be guessed at. A considerable number of other examples have been seen, some merely sand-filled, others containing rock fragments as well. In all cases the cement is calcareous and the rock weak and easily removed.

The above evidence of the character of the surface on which the Potsdam was deposited, is of precisely the sort so convincingly set forth by Wilson in his discussion of similar features in Ontario.¹ In New York these features are developed in a belt of considerable breadth across the strike, showing a great number of ridges and valleys, with patches of overlying Potsdam, and with the relief in every case owing to differential erosion on rocks of varying resistance, and in no case to subsequent folding. In this State exposed patches of residual materials resting on the old surface are more numerous than in Ontario, and these are in the depressions in all cases, showing that the depressions were in existence and served as receiving pockets for this material at the commencement of sandstone deposition. The evidence is abundant, clear and convincing that the Precambrian surface underneath the sandstone is precisely like that where the sandstone is absent, and that the present topography of the Precambrian areas is that resulting from recent stripping

¹ Wilson, A. W. G., Can. Inst. Trans. 7:146-55.

away of the sandstone; in other words that it is the reappearance at the surface of a topography of tremendous antiquity.

It further shows that this surface was little affected by the ice sheets of Pleistocene times, otherwise this identity of character could not have been so well retained.

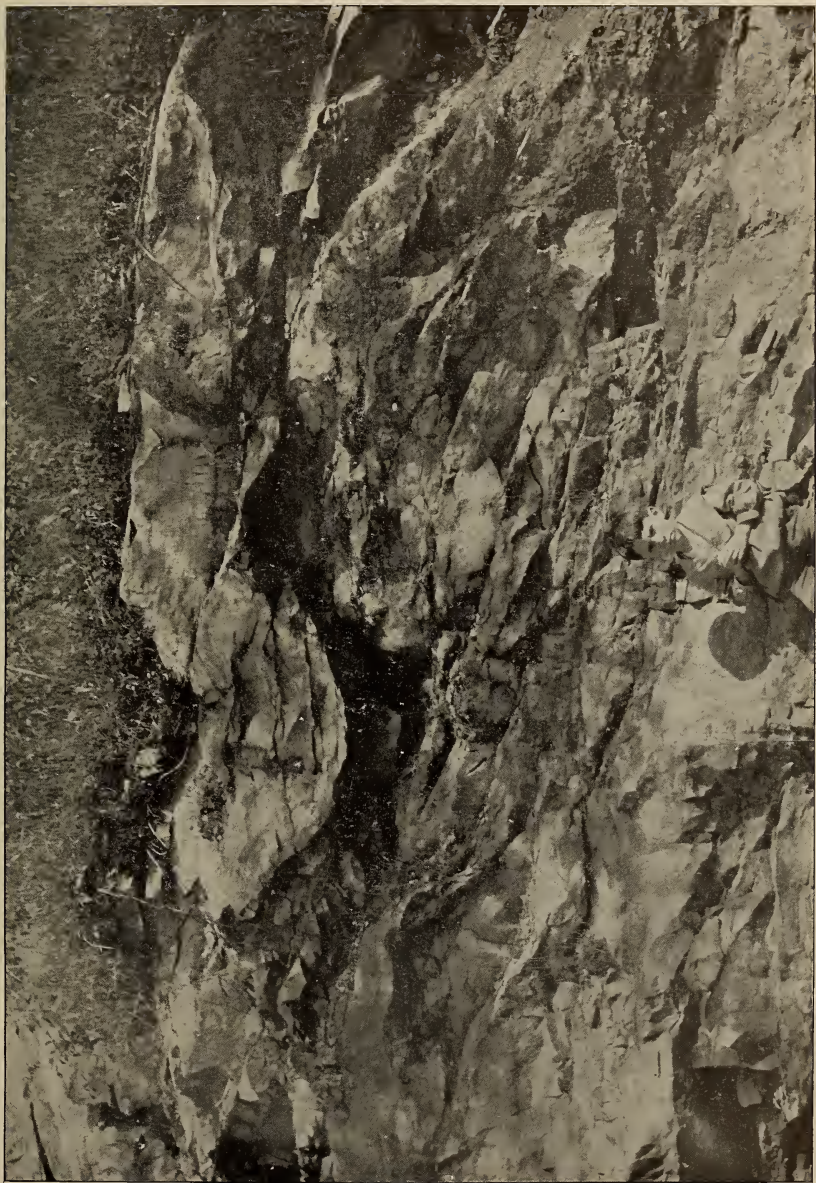
Except for the local accumulation of a very scanty amount of residual material in small pockets in the depressions (and this almost exclusively quartzose) the Precambrian surface, as it passes under the Paleozoics, is remarkably free from signs of surface decay, even the weak rocks being astonishingly fresh. In this respect also the conditions are like those noted in many places in Canada and the United States, as described by numerous observers.

The relief of the Precambrian surface under the Potsdam is much the same in character here as elsewhere along the northern and eastern borders of the Adirondacks, but is apparently less in amount than it is further east, where there are differences in level of three or four hundred feet at least. The evidence there, however, is complicated by the presence of numerous large faults and is by no means so well shown as it is here. On the south border, in the Mohawk valley region, the surface was much smoother than here, exceedingly smooth in fact.

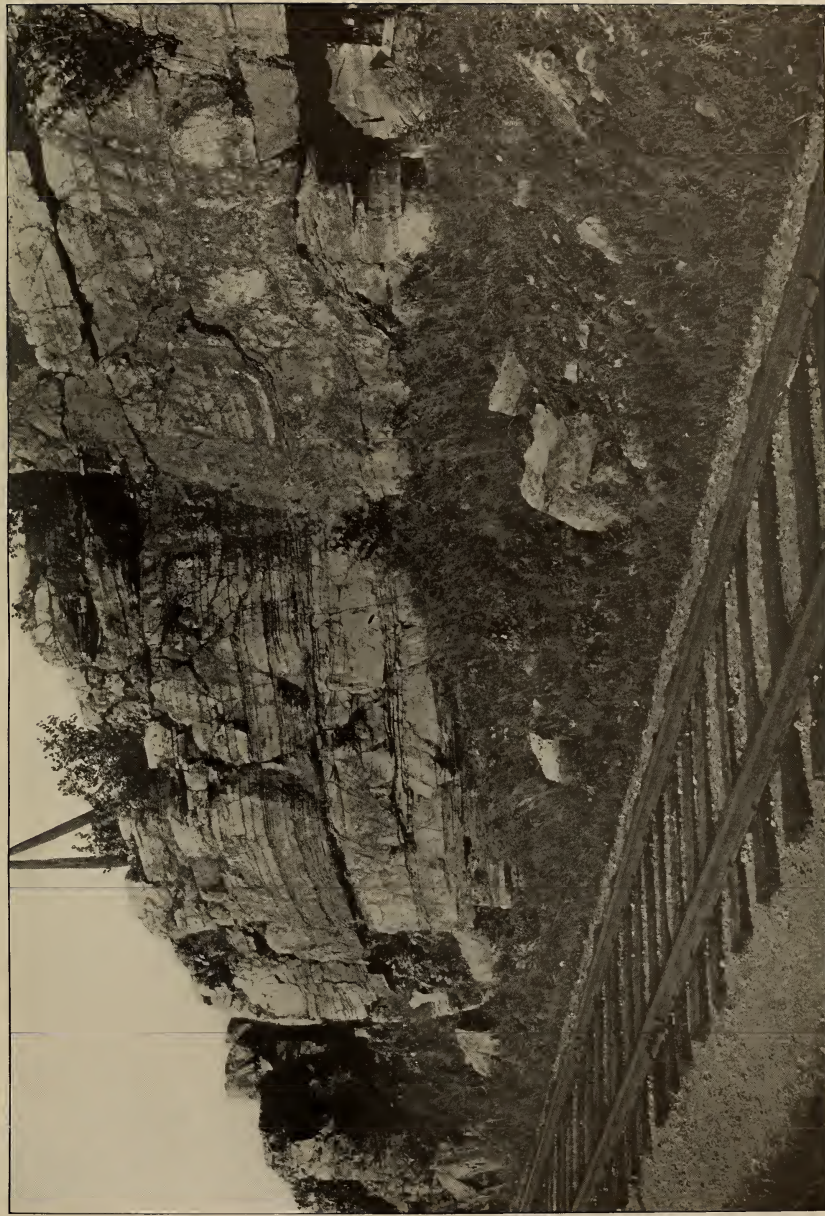
Potsdam sandstone

The first deposits laid down upon the worn Precambrian surface consisted of medium grained, quite pure quartz sand, now firmly cemented to sandstone. On the Alexandria quadrangle the formation attains a maximum thickness of about 125 feet. This thickness diminishes both southward and westward, but shows a steady increase to the eastward of the area mapped. Within that the thickness of the sandstone is not greatly in excess of, or else does not quite equal, the variation of level shown by its floor, so that it is subject to continual variation from place to place, and thins to 20 feet or less over the old ridge summits. On the Theresa quadrangle, and on Wellesley island, it locally failed to overtop the highest of these, and the Theresa dolomite is found resting directly on the Precambrian.

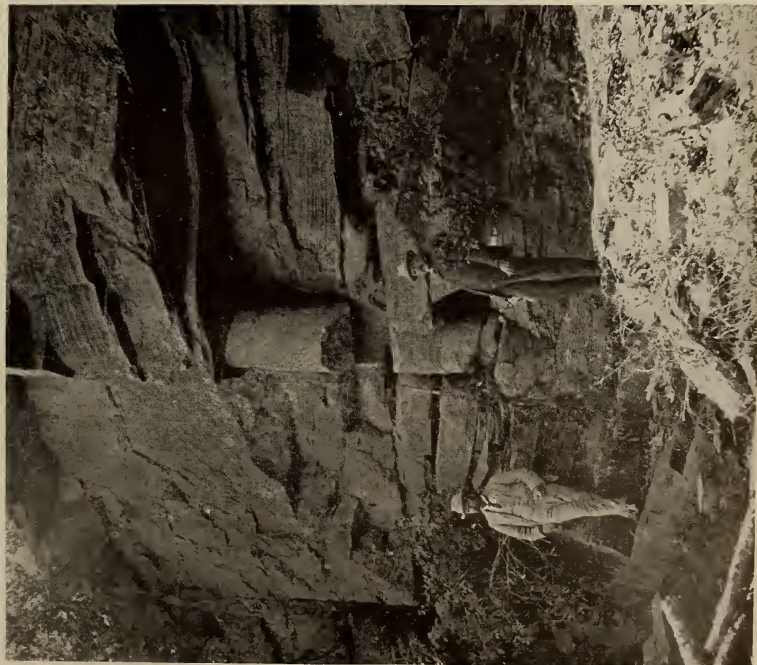
The bulk of the formation consists of a very pure quartz sand, quite thoroughly cemented with a silicious cement. The general color is light gray to buff, weathering white, but in the northern portion of the mapped area there is much red, or banded red and white rock in the lower half of the formation. The bulk of the formation is evenly bedded, and the greater part is thick bedded,



Potsdam sandstone in Theresa village just north of the lower bridge. Just to the right of the view its contact with the underlying Grenville limestone is exposed, the contact being on an irregular and sloping surface. The view illustrates the very irregularly bedded character of the Potsdam in such situations, which is certainly in part due to the irregularity of the floor on which it was laid down. H. P. Cushing, photo, 1906



Railroad cut in Potsdam sandstone 2 miles north of Theresa, looking east. Note its evenly bedded character as compared with plate 10; also the slight dislocation toward the right. H. P. Cushing, photo, 1907



Potsdam sandstone, Gildersleeve quarry, near Rideau, Ontario; red sandstone, somewhat banded with white. An excellent example of the "tree concretions" shows midway in each view. Right-hand photo by H. M. Ami; left-hand photo by Geological Survey of Canada.

with thinner bedded upper portions; where deposited on sloping surfaces the lower portion is often very massive, and quite irregularly bedded with a rude tendency to conform to the surface of deposit [pl. 11, 12]. Cross-bedding is present somewhat but in by no means prominent development. Ripple marks, however, abound. Much of the silicious cement has been deposited as secondary enlargement of the original quartz grains, the slides furnishing some beautiful examples of this.

Occasional long, cylindrical concretions (?) of a telegraph pole type appear in the sandstone, and are called "tree trunks" by the populace. As seen in cross section on rock surfaces they appear as circular portions of the rock, from 1 to 3 feet in diameter. On cliff sides they are long, vertical cylinders of sandstone. There is no perceptible difference in composition between them and the adjacent rock, but in every case the two are sharply separated by what may be for convenience styled a circular joint. No tendency to taper at the ends was noted, but the actual terminations were in no case seen. They certainly reach a length of 20 feet and may be considerably longer. Unless they represent a type of concretionary structure, we are wholly at a loss to account for them. If so they certainly are an unusual type both because of size and shape, and because of having the same composition as the inclosing rock. In plate 13 is shown an excellent example of one of them, in the Potsdam sandstone at Rideau, Ont., seen by us in 1908 under Dr Ami's guidance. This has been already described by the Canadian geologists, and is here introduced because, while corresponding precisely to the New York examples, it furnishes a much better illustration than any there seen.¹

Only at the base and the summit does the sandstone vary from these general characters. Basal conglomerates are present in but scant amount, with small thickness and patchy distribution. The majority of contacts show only a few, scattered quartz or quartzite pebbles in the basal layer of the sandstone. There are, however, frequent patches of coarse, basal conglomerates, especially on the Theresa quadrangle. They seem in all cases to occupy local hollows in the limestone valley floors, and to occur only where the limestone contained thin quartzite bands, or granite dikes. The pebbles are all sizes up to that of the fist, and show little or no rounding in most cases, being usually very angular. They consist chiefly of quartzite and of white granite, though in some cases pebbles of red, quartzose sandstone also occur. The cement is

¹Ells, R. W. Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 103.

calcareous in all cases. The angular form of the pebbles is due to the close jointing of the quartzite bands and granite dikes in the limestone, and the trifling amount of wear exhibited points to residual accumulation in the hollows, whereby they were protected from abrasion. The very small supply of such material, taken in conjunction with the small amount of decay shown by the underlying rocks, is a factor of much significance.

On the Alexandria quadrangle, both on the mainland and on Wellesley and Grindstone islands, a more extensive and bulky conglomerate occurs, which has already been described by Smyth [*see* pl. 14].¹ The most impressive display of this conglomerate known to us is that in the cliff along the St Lawrence in the extreme northeast corner of the Alexandria sheet where, rising sharply from the river level it reaches a height of 20 feet above it. Here, as usual, the deposit has a calcareous cement which dissolves away, loosening the cobbles, and giving an exterior resemblance to a cobbly moraine, while the adjacent river bottom is solidly paved with the material which has already weathered out. The deposit is everywhere very coarse, a cobble deposit rather than a gravel. In the exposure here the cobbles run up to a foot in diameter, and average probably 3 inches. They are round to subangular and consist exclusively of Grenville quartzite. Smyth notes the presence of a few small pebbles from the tourmalin contact zones, but agrees in asserting the entire absence of granite and schist material, though several of the conglomerate outcrops rest on these rocks.

In addition many of the exposures show that the conglomerate is not strictly basal, but has pebbleless sandstone beneath, up to a thickness of at least 10 feet; and in all cases the abrupt transition from sand to coarse cobble at both upper and lower contacts is one of the most interesting features of the deposit. Its coarseness, its abruptness, its horizon, and the lack of variety in material of the cobbles render it an exceedingly difficult deposit to explain.

There occur, in a few localities on the Theresa quadrangle, small patches of a dark red, very thoroughly indurated and vitreous sandstone which thus differs from the general run of the sandstone of the district, though similar rock occurs in the formation elsewhere, as in the Clarkson quarry at Potsdam. As it occurs here it seems to be distinctly older than the general formation. All seen of it was absolutely basal, nowherê was the thickness as great as 1 foot and it is only visible at actual exposures of the Potsdam contact on the Precambric. But all the sand-filled cracks seen in

¹ *op. cit.* p. 199.



Potsdam conglomerate, Wellesley island, nearly opposite Point Vivian, and south of schoolhouse 21. H. L. Fairchild, photo, 1908

the Grenville limestone were filled with this type of sandstone, and it occurs frequently as pebbles in the otherwise basal conglomerates, being the only sort of sandstone occurring as pebbles in such situation. The thorough induration seems certainly to have taken place before the pebbles were formed. There seems no way to account for these conditions except to assume that there was an earlier deposit of sand in the district, likely in no great amount, and chiefly in the Grenville hollows, deposition ceased, thorough cementation followed and then erosion; in other words that there was a slight amount of deposition here in earlier Potsdam time, separated by an erosion unconformity from the bulk of the formation.

Occasional beds of black, and of mottled black and white sandstone appear in the upper part of the formation. The coloring matter is entirely in the cement, which is silicious, and is wholly discharged at a low red heat, hence likely organic.

In the uppermost 10 to 15 feet of the formation calcareous cement reappears, foreshadowing the change which gave rise to the overlying dolomite formation. In consequence of this the rock weathers easily to a weakly holding, brownish sand, usually mottled with spots of deeper brown. This portion is mostly thin bedded but terminates above in a very massive layer, 2 feet thick or more, which is comparatively resistant owing to its massiveness; and this heavy, brown mottled layer often full of small, rounded sand concretions, makes a convenient summit for the formation, owing to its relative prominence. The first layer of gray dolomite usually comes in directly above, and if not, no more than a foot or two of sandstone intervenes. The two formations grade into one another, so that any line of subdivision must be an arbitrary one. We have drawn it at the base of the first dolomite layer to appear, and this closely corresponds with the summit of this thick sandstone. There is, however, some reason for the belief that the base of the upper, calcareous sandstones should be made the division line.

With the exception of the long trails of an unknown animal, to which the name of *Climactichnites* has been given, some of which have been found in the sandstone 1 mile west of Theresa, no fossils have been found in the formation in this district except in these upper, calcareous beds.¹ In these a large linguloid shell (identified by Ulrich as *Lingulepis acuminata*) is quite common, and passes up into the lower beds of the Theresa formation.

¹ Woodworth, J. B. N. Y. State Pal. Rep't 1902. p. 959-66.

Theresa and Tribes Hill formations

These formations, as mapped, consist chiefly of rather thin bedded layers of blue gray, sandy magnesian limestone which are exceedingly tough and resistant rocks when fresh, but weather rapidly to an ocherous, rotten stone [pl. 15]. The basal portion, through a thickness of 15 feet, carries frequent beds of weak, calcareous sandstone in alternation with the limestone, the sandstone being identical in character and appearance with that forming the summit of the Potsdam. These form apparent "passage beds" between the sandstone and the limestone above. The overlying beds consist chiefly of magnesian limestone though occasional sand streaks continue throughout, and there is a varying and, in general, considerable amount of sand in most of the beds. While this tends to have a streaky distribution, it seldom wholly gives out. The sand is chiefly of quartz, certainly 90% of it consisting of that mineral, but grains of feldspar, mica, magnetite, pyrite, titanite and zircon are also present and all in quite fresh condition.

All the rock effervesces freely with acid, and the thin section shows this to be chiefly due to the presence of calcite cement, most prominent in the more sandy portions of the rock. A prevailing and highly characteristic feature of the rock is the appearance, on freshly broken surfaces, of lustrous calcite cleavages. These are due to the coarsely crystalline character of the calcite cement, the crystals ranging from $\frac{1}{4}$ inch to 1 inch in length, and inclosing a number of sand grains, so that they are veritable sand crystals. This lithologic peculiarity is a feature of the rock of this horizon across the entire northern border of the Adirondacks.

As mapped the general thickness of the formation over the district is from 60 to 70 feet, but the thickness is variable. The thickness steadily diminishes to the west and to the south in the same fashion as the Potsdam's. But there are also local variations in thickness which are to be ascribed to wear of its summit during an erosion interval which separated its completed deposition from the beginning accumulation of the succeeding formation. For instance it has a thickness of but 20 feet near the north end of Perch lake (Theresa sheet) though recovering its normal thickness of 60 feet both to the east and to the west; and that the diminution in thickness is because of the wearing away of its upper beds with the production of a shallow valley is shown by the fact that the overlying formations thicken here by the same amount that the Theresa thins, and that the thicken-



Tribes Hill limestone in creek wall 1 mile west of Lafargeville, looking west. The fairly massive beds, with their tendency to weather into thinner bedded form are well shown. Height of section 15 feet. H. P. Cushing, photo, 1908

ing is due to the presence of basal layers which disappear to the east and west as the Theresa thickens.

The field work in the district was completed, and this report written under the impression that this comparatively thin formation was a unit and all of the same age. In its lower portion *Lingulepis acuminata* is abundant; above, specimens of a rather large, flat-coiled gastropod occur abundantly in places; occasional cystid plates are found, and unrecognizable traces of other forms. The horizon seemed the same as, and the beds identical with beds which directly overlie the Potsdam sandstone all across northern New York, a length of outcrop of 150 miles, and which have heretofore been called "passage beds" between the Potsdam and the Beekmantown, the Beekmantown being the formation which overlies the Potsdam for much of this distance. In the belief that no Beekmantown was present here, and yet that there was here a formation which required mapping separate from the Potsdam, the name Theresa was proposed for this magnesian limestone formation, it being well exposed in the township of that name.¹ Recent work by Ulrich, Ruedemann and myself in the Mohawk valley has, however, tended to throw much doubt upon the entire correctness of this position. We find that the formation in the Mohawk valley known as the Little Falls dolomite, and heretofore regarded as of Beekmantown age, is made up of two unconformable formations, the uppermost of which is of lower Beekmantown age, and is a quite fossiliferous limestone which we are proposing to separate and call the Tribes Hill formation; while the underlying dolomite formation is of Upper Cambrian (Ozarkic) age. Now the Tribes Hill formation contains, as one of its fossils, a gastropod (named *Pleurotomaria hunterensis* by Cleland) which Ulrich regards as identical with the gastropod from the Theresa formation; it also contains numerous cystid plates, and these he also regards as identical with those from the Theresa. The *Lingula*, however, occurs in the Little Falls dolomite, instead of the Tribes Hill formation, and is in fact a characteristic Ozarkic fossil all around the Adirondack region. Ulrich's present view is therefore that the Theresa formation, as here mapped, is in part of Ozarkic, and in part of Tribes Hill (lower Beekmantown) age. If this be true there must be an undetected unconformity between the two portions. In the field the only lithologic difference noted between the upper and lower portions of the

¹ Geol. Soc. Am. Bul. 19:155-76.

formation was the absence above of the sandstone beds which are interstratified with the limestones in the lower division. Otherwise the formation constitutes an apparent lithologic unit and appears as such on the maps; and it seems better to leave it as such instead of attempting to subdivide it at this juncture. If, however, it does consist of these two separate formations the necessity for the name largely disappears, and it is rather a pity that it was ever suggested. It is likely, however, to prove useful as a name for the considerable thickness of alternating beds of sandstone and magnesian limestone which everywhere immediately overlie the Potsdam sandstone in northern New York, and which should be mapped separately.

There is then some reason to believe that there is present in this district a thickness of from 20 to 30 feet of limestone of lower Beekmantown age, quite like a similar thickness of rock at the summit of the Little Falls dolomite at Little Falls (where an unquestioned unconformity exists between the two), and holding the same fauna. This is to be separated from the Little Falls dolomite under the name of the Tribes Hill limestone, and the same separation needs to be made in this district. The Theresa formation is to be restricted to the alternations of sandstone and magnesian limestone which constitute the lower half of the formation as mapped.

Age of the Potsdam and Theresa formations. These two formations, with a maximum thickness in this district of from 125 to 150 feet only, represent the attenuated western edge of formations which, in the Champlain valley, have tenfold that thickness. Their distribution shows that they were deposited in a subsiding trough along the present St Lawrence valley line, and that their deposit commenced at the east and worked westward. Everywhere along this line we find a sandstone beneath, grading upward into an overlying dolomite, and everywhere the horizon is characterized by the presence of the fossil *Lingulepis acuminata*. Everywhere along this line too there seems to be a break between these formations and the next formation above. The two formations seem then to be indissolubly bound together, to rest unconformably on the Precambrian, and to be separated by an unconformity from the overlying formation. Since the formations are thin in the immediate district, and are thinning to the west and south, it follows that we are here in the vicinity of the western edge of the subsiding trough. Just how far west its deposits extended can not be told. According to

Ells the Theresa formation outcrops on Howe island, and on the Canadian mainland to a point midway between Gananoque and Kingston.¹ In the district about Kingston, as seen by us in 1908 under Dr Ami's guidance, the Potsdam is certainly present, though no Theresa was seen. The Potsdam is in patchy distribution, in depressions of the old Precambrian surface, and is still thinner than it is at Clayton. The Theresa may never have been deposited here, or it may have been thinly laid down and then eroded, prior to Pamela deposition. But it certainly seems as if, here at Kingston, we are very near the westerly end of this old, St Lawrence, Upper Cambrian trough.

On the basis of its fauna and position the Potsdam sandstone of northern New York was classified as of Upper Cambrian age by Walcott, and in this he has been followed by practically all geologists. One can start on the formation at Lake Champlain and follow it without a break to Clayton, as a single continuous sandstone formation. Unquestionably its deposition commenced first at the east, and gradually extended westward; unquestionably the basal portion in the western sections is younger than the base in the east. But, so far as known to us, there is not a scrap of evidence to show that the deposition of sand had ceased, and that of dolomite begun on the east, before sand deposit had even commenced on the west. And even were this true, as is quite possible, there is certainly no evidence of such considerable age difference between the eastern and western ends of the formation, as to warrant their classification in two entirely different geologic periods, the one end Cambrian, the other Ordovician, as has been recently done by Professor Grabau, who classes the Potsdam here as of Beekmantown age.² That seems to us a stretching of facts to fit theory that is certainly not permissible. It is quite possibly true that the sandstone deposition slowly worked its way westward by progressive overlap, as the trough continued to subside; but the evidence seems to us to indicate clearly that the length of time consumed in the process is far less than Grabau would have us believe. We have now gathered evidence from many points in New York indicating that everywhere the Beekmantown formation is unconformable on what lies beneath. Detailed study of section after section has shown the presence of the unconformity in every case; and though the

¹ Roy. Soc. Can. Trans., ser. 2, v. 9, § 4, p. 97-108.

² Science, n. s. 29:356-58.

work is only begun we are strong in our belief that uplift of the whole region preceded the Beekmantown.

The type locality of the formation, at Potsdam, is precisely midway between Clayton and Lake Champlain. If one of these ends is of Potsdam, and the other of Beekmantown age, it is of interest to conjecture what the age may be at the type locality.

To the writer it has long seemed clear that the sandstone and the overlying dolomite must be classed in the same period, not only here on the west but everywhere in northern New York. By the overlying dolomite is meant not the true Beekmantown formation, but the dolomites which underlie this and which, the evidence indicates, underlie it everywhere unconformably. These dolomites have heretofore been classed with the Beekmantown and constitute Brainard and Seely's "Division A" of that formation in the Champlain valley, with the underlying "passage beds." But while the beds of this division grade downward into the Potsdam they are separated by an unconformity from the beds of "Division B" just above, as recently shown by Ulrich; because of which the writer has recently argued that, since this unconformity is everywhere present in New York, marking the emergence of the entire region, it forms the logical plane of division between the Ordovician and the group beneath. If this contention be well founded, the Potsdam and Theresa formations, the Little Falls dolomite, and "Division A," fall into the upper Cambrian group of present classifications. Ulrich has, however, recently proposed a different classification, involving the insertion of a new group of period rank between the Cambrian and Ordovician, for which he proposes the name "Ozarkic," and into which the Potsdam and Theresa formations would fall. For many reasons the writer is in accord with this suggested innovation.

Pamelia formation

In our district here the Theresa formation is everywhere overlaid by the limestone group here called the Pamelia formation. This is in some respects the most interesting formation in the section since it represents the thinned, shoreward edge of a formation which, while widespread elsewhere, has not heretofore been recognized in New York, and is in existence as a surface formation in the State only in this immediate area. Because of its wide separation from other areas where the formation appears, and because it represents only a local facies of the

mere upper part of the whole, the giving of a local name seems justified, and in Pamela township the entire thickness is exposed. As has been shown there is plain evidence of an erosion interval between this and the Theresa, indicative of uplift to above sea level and of erosion on this land surface. As will be later shown this is an important and widespread break. The comparatively slight amount of erosion is indicative of low altitude for this land surface.

The renewed depression which initiated Pamela deposition came in from the southwest instead of from the east, involving change in the direction of slope of the surface.

The formation consists essentially of limestone, though much of it is not pure limestone. It is conveniently separable into lower and upper divisions which differ in lithologic character. The lower division has always a sandy base, followed by alternations of black limestone, blue limestone and gray (somewhat magnesian) limestone, often with shaly partings between the beds. The upper division contains much whitish, earthy limestone, with interbedded dove limestone and gray magnesian limestone. The black limestone characterizes the lower, and the earthy and dove limestones the upper division.

In the western portion of the Theresa quadrangle the formation has a thickness of 150 feet or more. Traced eastward across the quadrangle it thins considerably, and on the eastern margin appears to have less than half this thickness though here the drift is so heavy, and exposures so poor, that no good measurements can be obtained. However, 60 feet seems a generous allowance for the thickness here, and it is the beds of the lower division which have disappeared.

Following the formation westward, across the Clayton quadrangle to its disappearance beneath the river, the belt of outcrop swerves somewhat to the north, and the formation thins somewhat in this direction also. If it could be followed due west across the quadrangle it would no doubt hold its thickness or even perhaps increase. It is the northward shift that causes the thinning. A thickness of at least 80 feet is maintained to the river however, and the formation passes across into Canada with this amount not materially reduced. The shore lines of this depositional basin then lay not far distant to the east and north of the district and the invasion of the sea must have come from the opposite direction.

In the immediate district the formation rests everywhere on the sandy dolomites of the Theresa. In the district about Kingston it

rests either on the Potsdam or on the Precambric. In the upper Black river valley it lies on the Precambric. All these formations are capable of furnishing sandy material and hence the sandstone base of the formation is but natural. The Theresa, however, is less capable in this respect than are the other formations, thus accounting for the fact that this sandy base is a less prominent feature of our area here than it is in the others.

Hereabout, the best section of this basal material seen is at the foot of the Pamela inface, 2 miles east of Perch lake, Theresa sheet. The small creek there runs over a massive, bared layer of Theresa dolomite, above which a 14 inch layer of the same shows in the bank. Above this lie weak, greenish sands and sandy shales, with an exposed thickness of some $7\frac{1}{2}$ feet, the basal layer somewhat pebbly and more massive than the remainder. The cement is calcareous and abundant. The rock is therefore weak and seldom exposed, yet in a sufficient number of places, and sufficiently well to show that it everywhere underlies the limestone throughout the district with a thickness of from 10 to 15 feet, much of which is shaly. It is a more calcareous, and vastly weaker rock than even the most calcareous beds of the Potsdam, and quite different from it lithologically; so unlike in fact that the two rocks can be readily distinguished from one another by lithologic character alone throughout the whole region. This becomes of importance in the region around Kingston, where in our opinion both sandstones are present but without the separating Theresa formation. The Pamela basal sandstone rests, now on the Potsdam and now on the Precambric, is less shaly and attains greater thickness than on the New York side, and shows at times astonishingly coarse basal conglomerate. In its green color, weathering to a red mottling, in its abundant calcareous cement, and in its weakness, it corresponds exactly with the New York rock, while the silicious Potsdam beneath also corresponds with the Potsdam across the river in every minute lithologic detail, even in the "tree" concretions.

In the upper Black river valley both Potsdam and Theresa are absent and the Pamela rests on the Precambric. At Martinsburg the wonderfully complete section shows a thickness of 19 feet for the basal sandy portion, weak green sandstone, blotched with red, abundant calcareous cement and with thin conglomerate at the base.

Where thickest, the limestones of the lower division show, above the basal sandstones, beds of gray, magnesian limestone with frequent shale partings; these are followed upward by black, fossiliferous limestones, holding a rather abundant marine fauna; then

succeed alternations of blue limestone and gray, magnesian limestone, with occasional white; earthy beds, and with thin recurrences of the blackish limestones with traces of the marine fauna; in the other beds the fossils are chiefly, or exclusively, ostracods. As the formation thins to the east and west the lower gray beds disappear, bringing the basal sands up under the black limestone; with further thinning this disappears in its turn, but at the same time the higher black layers seem to show increased thickness and prominence, so that where the lower division has been thinned to a few feet, as it has over much of the region, it is still characterized by black, fossiliferous limestone.

This lower division has a measured thickness of 70 feet in a nearly complete section by Perch lake. It is likely somewhat thicker to the west but probably does not exceed this more than 15 or 20 feet. A well near Stone Mills was drilled 125 feet in the formation without reaching the base, but drilling commenced in the upper division and how large a part of that is involved is not known, though likely 50 feet must be allotted to it.

The upper division consists of alternations of white earthy limestone, and of dove limestone, with occasional beds of gray, and of blue, hard, subgranular or subcrystalline limestone; there is also some yellow, earthy limestone, and a horizon where a reddish tinge is likely to prevail. The summit is chiefly of dove limestone. The earthy limestones hold numerous nodules of coarsely crystalline calcite, which attain quite large size in some of the upper layers, with diameters of from 3 to 5 inches. Celestite nodules also occur, but much less frequently. Much of the upper division is thin bedded, weathering into small, yellow stained slabs an inch or two in thickness; and the stone walls of this thin material which line the roadsides and separate the fields everywhere characterize the upper Pamela country.

The surfaces of many of the layers are covered with shrinkage cracks, especially in the upper part of the division. Sand grains also appear in some of the white, earthy beds. Abundant Styliolites occur at certain horizons in the upper dove limestones. The evidence of estuarine, or lagoon deposition, with evaporating waters, occasional exposure of broad mud flats, and from time to time replenishment of the water from the sea outside, freshening it and bringing in traces of the outer marine fauna to mingle with the ostracod fauna of the lagoon, is very plain and conclusive; prevalence of somewhat arid climate is also suggested. The rock is very like, and the climatic and depositional conditions very simi-

lar to those which prevailed during the formation of the Siluric waterlimes of central New York.

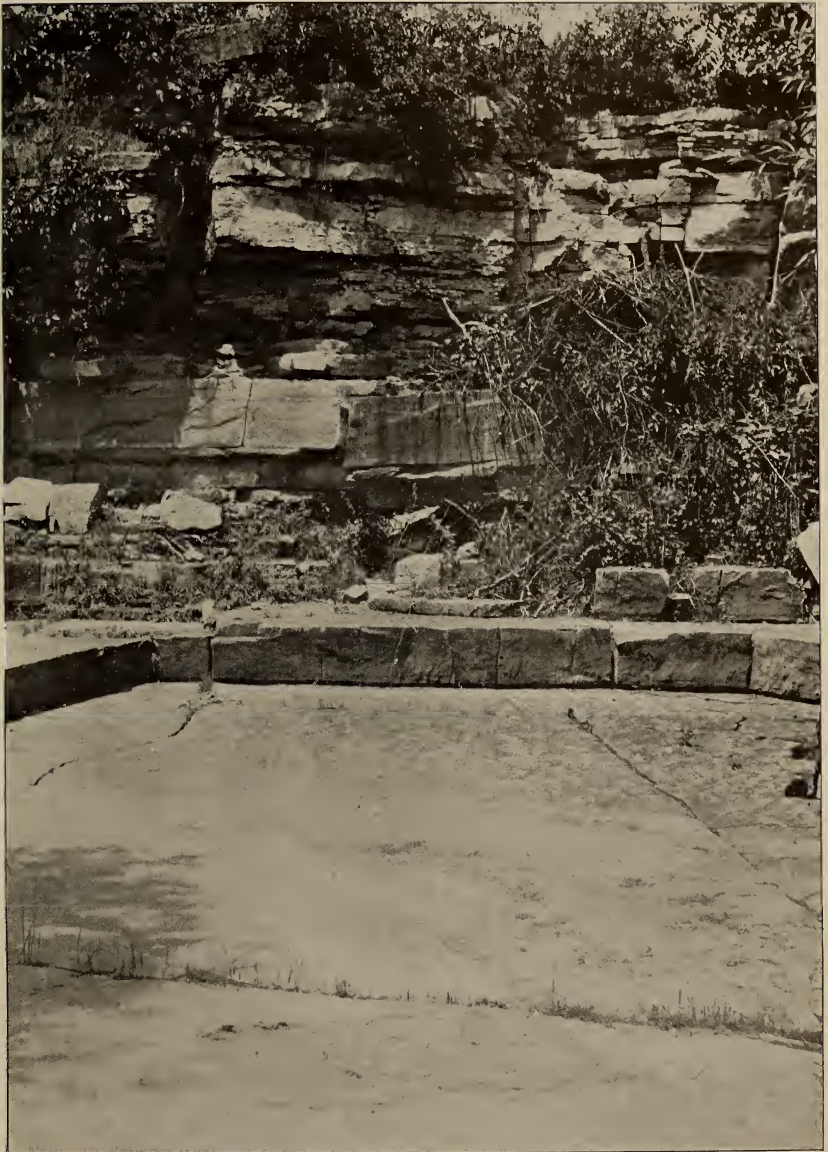
The thickest measured section of the upper division, 1 mile southwest of Depauville, Clayton sheet, gave a thickness of 82 feet. The contact with the overlying Lowville was shown, and the base of the section can not have been greatly above the base of the upper division. Near the river west from Clayton a similar thickness was found, though the upper part of the section was considerably interrupted. In all probability the thickness does not vary greatly from this over the entire map limits, with the exception of the eastern margin of the Theresa quadrangle. The thickness of the two divisions together then indicates a maximum of about 150 feet for the formation hereabout.

The fauna of the formation consists chiefly of ostracods, which are found at all horizons, and Ulrich remarks on the absence in the formation of certain large sized species of *Lepeditia* and *Isochilina* which occur in the Lowville above. The marine fauna of the lower division includes gastropods, cephalopods, lamelli-branches, trilobites, corals and sponges. The most abundant and characteristic form is the coral *Tetradium syringoporoïdes*, which abounds in certain layers of the black limestone. The most common trilobite is a species of *Bathyurus* which is very like the common *Bathyurus extans* of the Lowville, but which Ulrich distinguishes as a different and unnamed species, which is a common Stones River form. Among the gastropods he identifies *Lophospira perangulata*, another *Lophospira*, and a *Helicotoma*. The fauna as a whole is quite similar to that of the Lowville, though the differences are characteristic.

Since the formation is a new one to the State the publication of a few detailed sections is advisable. The best continuous section of the lower division is found in the bed of a small creek which tumbles down the steep bluff face east of Perch lake (Theresa sheet), cutting the 400 foot contour where the figure 400 appears on the map.

6'	White, earthy limestone in thin beds, often shaly looking
3' 6"	Brittle, tough, blue to blue black limestone, thick bedded
1' 1/2"	Gray, subgranular, magnesian limestone, weathering white
1' 5"	Massive bed of blue, subcrystalline limestone
1' 3"	Massive bed of gray, magnesian limestone
5"	Blue, subcrystalline limestone
1' 8"	Gray, magnesian limestone, two layers
1'	Concealed
3'	Finely laminated gray to blue gray, magnesian limestone, fine-line weathering on edges
10'	Concealed
10' 3"	Black to blue black, fossiliferous limestone, upper 3 feet thin bedded, remainder fairly massive

Plate 16



Exposure $1\frac{1}{4}$ miles east of Perch lake, of limestones of the lower division of the Pamela formation; about 6 feet of black, fossiliferous limestone above and twice that thickness of gray, magnesian limestones beneath. H. P. Cushing, photo, 1907

8'	Gray magnesian limestone, weathering whitish, fairly massive below, upper 2 to 3 feet thin bedded and earthy
1' 6"	Curdled looking intergrowth of blue limestone and gray, magnesian limestone, the former weathering most rapidly with production of fantastic weathered surface
19'	Alternating, gray, earthy, impure magnesian limestones, and thin, shaly looking partings, limestone weathering at times to a greenish tinge, at other times whitish
2'	Greenish to olive, calcareous shale
2'	Greenish, calcareous sandstone, coarse, well rounded sand grains set in calcite paste
<hr/>	
72'	1/2"

The lower 4 feet of the section belong with the basal, sandy portion of the formation, without any question, so that the actual base is nearly reached. Above is a thickness of 28 feet of impure, magnesian limestone before reaching the base of the fossiliferous black limestone, the most characteristic member of the lower division. Plate 16 is a photograph of beds of this horizon exposed in the creek bed just north of the road 1 1/4 miles east of Perch lake. In the section here 14 feet only of gray magnesian beds are found underneath the black limestone, as against the 28 feet of the Perch lake section. A mile further east these have disappeared letting the black limestone down on the basal sand beds, or rather bringing them up to it.

Judging from other sections the concealed 10 feet of the section is occupied by weak, earthy, thin bedded, whitish limestone, and the section would be capped by a very massive, blue, subcrystalline limestone which forms a strong shelf everywhere through the district.

The best sections of the upper division are all on the Clayton quadrangle. One measured up the bed of the small creek which tumbles down the bluff into the Chaumont river a mile southwest of Depauville is as follows:

1'	8"	Brittle, light gray, subcrystalline limestone
16'	1"	Thin bedded, brittle limestone, mostly dove, but with beds of grayer limestone
1'		Massive layer of dove limestone
10'	8"	Irregularly bedded, gray to white, earthy limestone, mostly thick bedded; midway is somewhat sandy
5'		Thick bedded, uneven, gray limestone
3'		Thin bedded dove limestone in 3" to 6" layers
4'	2"	Gray white, earthy, irregular limestone, both thick and thin beds
5'	4"	Dark and light gray, brittle, subcrystalline limestone
1'	8"	Gray white, impure, earthy limestone
1'	8"	Brittle, blue gray, subgranular limestone
5'	10"	Impure, earthy, white limestone, irregularly bedded
1'		Hard, blue gray, subcrystalline limestone

57' 1"

The section terminates downward 20 feet above the river level. Above, after a 10 foot gap, come 15 feet of thick and thin bedded, dove limestone, often mud cracked, and then the Lowville base, giving an 80 foot thickness to the section. It is not certain whether its base overlaps the summit of the previous section of the lower division or not, though it is thought not. But the uppermost 6 feet of that section belong to the upper division and the thickness is nearly the same as that of the impure, earthy limestone at the base of this section. Even granting that amount of overlap, the two sections taken together give a *certain* thickness of 150 feet to the formation and this may need to be increased by from 10 to 20 feet.

Another most excellent section is that given in a quarry up the river bluff 4 miles west of Clayton [pl. 17]. A slightly generalized statement of it will serve the purpose here.

- 1' 8" Thin bedded, dove limestone
- 5' 6" Gray white, impure earthy limestone, mostly thin bedded, some thick and irregular beds
- 7' 5" Rather massive limestone beds averaging 20" in thickness, gray in color, in part earthy, in part subcrystalline
- 2' 9" Dove limestone, three beds, the lower thick, the two upper thin
- 3' Hard, gray, subcrystalline limestone, two thick beds with a thin shaly parting between
- 1' 5" Dove limestone, two beds
- 1' 8" Hard, gray limestone, upper inch is shale
- 1' 8" A hard, dove limestone layer
- 1' Gray white, earthy limestone, thin bedded
- 2' 9" Brittle, gray, subcrystalline limestone
- 1' 8" Massive, dove limestone bed
- 11" Thin bedded, whitish, earthy limestone
- 1' Gray, subcrystalline limestone, slight pinkish tinge
- 7' 1" Gray, earthy limestone in thick beds with shaly partings; a thin dove layer near the top; reddish tinge at times
- 9' 6" Blackish limestone, upper bed very massive

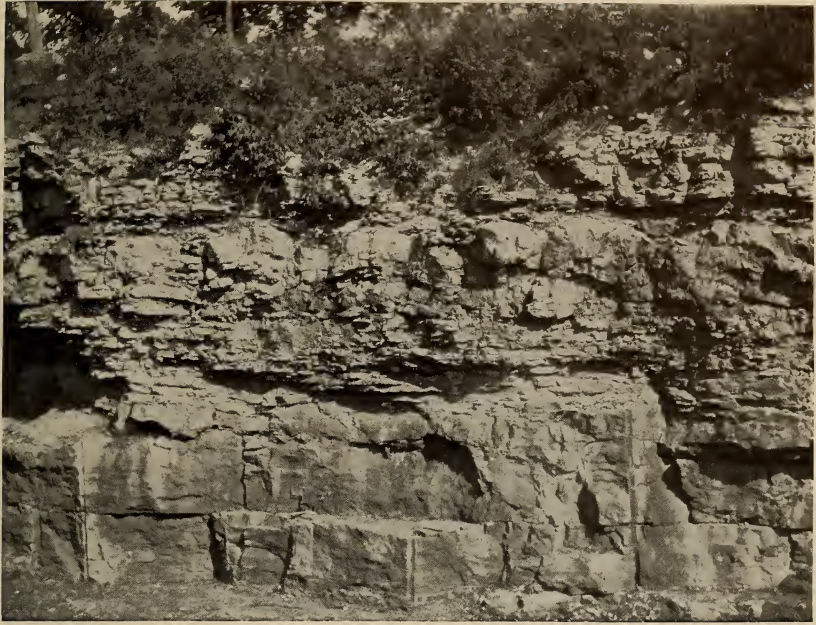
49'

The black limestone at the base of the section seemed to the writer to smack strongly of the lower division, though the marine fauna was but feebly developed, and Ulrich expressed doubts in the matter. Certainly beds of the type are not usually found in the upper division. A short distance back from the river another quarry shows a thickness of 15 feet of the succeeding beds, the entire thickness being of dove limestone, both thick and thin beds, with sparing fossils. Further back, by the roadside is a shallow quarry exposing 4 feet of still higher beds, two massive dove layers with similar but thinner beds between, the thick beds holding *Phytopsis*. Such beds elsewhere mark the extreme summit of the *Pamelia*. Were the upper part of the section complete there would be shown here a thickness of more than 80 feet belonging to the formation.

Plate 17



Quarry in the upper Pamela formation, by the river 4 miles west of Clayton; alternating beds of dove limestone, and whitish, earthy limestone. The upper view is a somewhat more distant one showing a greater thickness of the upper beds. Photo (upper) by H. M. Ami and (lower) by E. O. Ulrich, 1908



Upper view. Dove colored limestone beds of extreme upper portion of Pamela formation in railroad cut just south of Sanford Corners. Theresa quadrangle, looking east.

Lower view. Contact of Pamela and Lowville formations at the south end of the railroad cut. E. O. Ulrich, photo, 1908

Both these sections are imperfect in their showing of the beds of the extreme summit. The most excellent section shown in the railway cuts just south of Sanford Corners (southeastern part of Theresa quadrangle) supplies this deficiency [pl. 18].

- 1' 4" Two 8" layers of blue gray, crystalline limestone, abundant lamelli-branch casts full of crystalline calcite; dove limestone mud balls
- 1' Mud cracked, argillaceous, somewhat granular, bluish limestone, weathering yellowish
- 1' Thin bedded, blue, granular limestone, conglomeratic, quite shaly below, very fossiliferous, chiefly bryozoa; base of Lowville
- 11" Dove gray, fine, impure limestone, weathering light
- 3' 2" Laminated, mud cracked, gray dove, argillaceous limestone, thin bedded, ripple-marked, worm-burrowed
- 1' 9" A 6" layer below and an upper 15" bed; fine dove limestone with calcite spots, gastropods and cephalopods
- 1' 10" Gray, granular limestone, crystalline specks and spots; shaly below, more massive above
- 5' 6" Finely granular, blue dove limestone, shaly below, more solid above; blocky weathering; calcite seams and spots; sparse *Phytopsis* in upper part
- 4' 6" Mottled, blue dove limestone, thin bedded above and below; much crystalline calcite replacing poorly preserved fossils
- 8" Blue black, finely granular, dove limestone; calcite spots
- 1' 10" Blue gray, calcareous, sandy shales, weathering yellowish
- 7" Dark blue, finely crystalline limestone; conglomeratic
- 8" Blue gray, calcareous shales, weathering yellowish; sand grains
- 8" Blue dove limestone; base weathering sandy looking
- 9" Sandy, argillaceous, shaly limestone, weathering yellowish
- 9" Blue dove, mottled limestone
- 3' 1" Gray blue, dove limestone, somewhat muddy, shaly fracture
- 7" Blue dove limestone, small limestone pebbles
- 1' 9" Solid layer of blue dove limestone, rudely laminated with organic streaks
- 1' 10" Laminated, argillaceous, fine grained, mottled, blue dove limestone; two seams
- 1' 4" Fine, flinty, dove limestone; slightly conglomeratic at base
- 1' 10" Fine, flinty, dove limestone, with a shaly streak of 3"; lower portion with *Phytopsis*
- 4' Rather compact, fine dove limestone; a little *Phytopsis* in the upper 3"
- 1' 2" Blue dove, thin and irregular bedded limestone
- 2' 6" Measures concealed
- 5" Blue dove, mottled, laminated limestone, small ostracods
-
- 45' 5" Of which the lower 41' 8" belongs to the Pamela

The 1 foot layer, third from the top of the section, is divisible into an upper 3 inch portion, full of fossils, making an irregular contact with the remainder, which lacks fossils, and in Ulrich's judgment, with which we coincide, the line between the two formations is properly drawn at that slight break. These upper dove limestone layers, over 40 feet thick in this section, have puzzled us much and have been difficult to classify. They are above the white, earthy beds which are the most characteristic lithologic feature of the upper Pamela, and while they are precisely like the dove limestones

which are intercalated with these, they are also very like the Lowville, with which we at first classified them. Their shift from the one to the other considerably diminishes the supposed thickness of the Lowville of the district and correspondingly increases the Pamela.

In this cut, the first of three such along the railway south of Sanford Corners, the rock dip is to the south, carrying the Pamela summit below the track level before reaching the second cut. The dip then reverses, becoming north, and bringing up the Pamela again in the third cut. At the north end of this cut the basal, bryozoan, conglomerate layer of the Lowville has increased in thickness to 38 inches, as against a 3 inch thickness in the section just given, and immediately beneath it is a layer of exceedingly fine grained dove limestone mud, which is the exact counterpart of the material composing the conglomerate pebbles [pl. 31, lower figure]. This layer was wholly lacking also in the previous section. At the south end of the cut the Lowville shows $6\frac{1}{2}$ feet thickness of basal layers which did not appear in the section in the north cut, and there is also a thickness of full 6 feet of the pebble-furnishing, dove limestone at the Pamela summit, which is also lacking in that section. The evidence of unconformity between the two formations is clear, and found as Ulrich had predicted that it would be. The fact that both formations thicken together is, however, somewhat unusual, and suggests that some of the warping shown occurred in the uplift following Pamela deposition, its summit being protected from wear in a shallow trough, in which also the first beginnings of Lowville deposition took place.

The section here in the south cut is given on page 84 under the account of the Lowville formation.

The section just described gives an excellent idea of the depositional conditions which prevailed during the closing stages of Pamela deposition. The fine limestone muds, much sun cracked, worm-burrowed, even ripple-marked; the injection of sand grains and the occurrence of the occasional limestone conglomerates, together with the abundance of ostracods and the general absence of marine forms; all these point unquestionably to intermittent deposition in a shallow lagoon, with drying mud flats produced from time to time, and with only occasional admission of sea water. Though the uppermost break, here chosen as marking the base of the Lowville, seems much the most considerable of all, the presence of more than one conglomerate horizon, of more than one horizon of sand grains, indicates several minor breaks in the summit of the

formation, and much complicates the successful working out of the section.

Extent of the Pamelaia formation. In a preliminary paper published some months ago, based on the field work up to the close of 1907, the writer attempted to predict the extent of the Pamelaia formation in New York and adjacent Ontario, in so far as the published literature warranted. The result of the field work of 1908 necessitates some modification of the statements there made, all of which prove to have been too moderate.¹

The study of the formation on the Clayton sheet, and the work about Kingston, show that the formation does not thin as rapidly in those directions as had been supposed. About Kingston the formation has much prominence and considerable thickness, much of the upper division, and the basal sandstones being well represented. The upper dove limestones of the New York section are here capped by thin bedded, earthy, shaly layers, weathering yellow, above which the Lowville comes in, with its basal conglomerate. The division plane between the two formations is therefore much easier of recognition than on the New York side.

Up the Black river valley we measured sections at Lowville and on Roaring creek, near Martinsburg, the latter a wonderfully fine, continuous section from the Precambrian up into the Trenton. We were at the time ignorant of the fact that Prof. W. J. Miller was engaged in the areal mapping of the Port Leyden sheet, on which this section occurs. That being the case its detailed exposition is left for him.² Suffice it to state that it shows a thickness of 72 feet, 6 inches of Pamelaia, overlaid by 54 feet, 7 inches of Lowville; and that, of the Pamelaia, the lower 19 feet is of sandy beds, followed by 8 feet of blackish limestone with abundant marine fossils, the remainder showing alternating beds with the characters of the upper division though the upper dove beds are lacking. Miller reports that the formation is traceable to the south line of the Port Leyden sheet, but does not appear beyond. This is, however, well toward the upper end of the Black river valley, and gives the formation in New York a measured length of outcrop of 70 miles, from southeast to northwest. The Kingston occurrence adds 15 miles more to this distance, and it is quite probable that the formation may run west for some miles across the Ontarian peninsula.

Our work was done, and a preliminary paper published, while in ignorance of the existence of a paper by Dr Ells upon the adjacent Canadian district. This paper, as the quotation which follows will

¹ Geol. Soc. Am. Bul. 19:165-71.

² N. Y. State Mus. Bul. 135, p. 22, 23.

show, distinctly recognizes the chief physical oscillation of the region.

It would, therefore, appear that some marked but well defined change of level occurred in the area south of the Kingston-Brockville Archaean axis at the close of the Potsdam, which was also materially reduced in thickness. This is in marked contrast to the conditions which prevailed north of that axis throughout the Ottawa basin; and it may be supposed that, at a certain stage in the deposition of the sandstone formation, the surface was raised above the level of the sea, and so remained till the beginning of Black River time throughout the whole extent of Lake Ontario.¹

Age of the Pamela formation. Our section here shows the Pamela formation to lie between the Theresa and Lowville formations, separated from each by an unconformity, the lower of which is much more important than the upper. In the Champlain valley two great formations, the Beekmantown and the Chazy, with a combined thickness of 2000 feet, occupy this same interval, yet the Pamela formation is unlike either. On the basis of its position and fauna, Ulrich correlates it with the upper part of the Stones River formation, a formation of Chazy age, but laid down in a separate basin from the Chazy, so that faunally and lithologically the two are quite distinct. The Stones River basin lay to the west and southwest of the Chazy trough, and was much larger. The barrier between the two in New York comprised the Mohawk valley region, much of the Adirondack district, and at least the westerly portion of the St Lawrence trough.²

Curiously too, although much sedimentation occurred in the Champlain trough during Beekmantown-Chazy time, and only Pamela deposit in our district here, yet this is practically un-

¹ Roy. Soc. Can. Trans. ser. 2, v. 9, § iv, p. 106.

It is to be noted that Black River is here used in a general sense as including the whole body of limestone.

² Since the above was written another paper by Professor Grabau has appeared which presents more definitely his interpretation of the rock succession and age in this district [Jour. Geol. 17:211-261]. The fundamental difference between us seems to be that he regards the break between the Theresa and Pamela formations as representing the somewhat expanded westward continuation of the break in the Champlain valley between the Beekmantown and Chazy, and recognizes no break there between the Cambrian and Beekmantown. We regard it as representing most of Beekmantown and all of lower and middle Chazy time and think that, to the east in the St Lawrence valley, it splits into two breaks with a wedge of later Beekmantown inserted between. He thinks there is no Cambrian here, and that the Potsdam and Theresa are of Beekmantown age; and he recognizes no break between the Cambrian and Ordovician. We find evidence of a considerable series of oscillations of level in the general region, while he argues, if we correctly understand him, for a slow, progressive subsidence of the region during Potsdam and Beekmantown time.

represented in the Champlain area, Ulrich correlating the dove, reef limestone, only a few feet in thickness, which forms the basal member of the upper Chazy there, with the Pamela horizon. In the much more complete sections about Chambersburg, Pa., a 200 foot thickness of limestone with an upper Chazy fauna, separates the Pamela horizon from the Lowville. Subsidence apparently ceased in the Champlain basin during the time of Pamela depression and deposit in this district, and as this ceased here, upper Chazy depression was renewed there, the unconformity between the Pamela and Lowville representing this upper Chazy interval. Knowledge of this led Ulrich to predict the unconformity and induced the search for it. Otherwise it might easily have escaped our notice.

Mohawkian series¹

The Mohawkian series comprises the Black River and Trenton groups. The Black River group is composed of the Lowville beds including the Leray limestone, and the Watertown limestone. In giving to the Black River group this larger scope, we return to the original conception of several of the geologists of the First Geological Survey of New York, i. e. Hall, Vanuxem and Mather, with the exception that the Black River then also included the Chazy limestone. Emmons, however, to whose district the Black River region belonged, did not use the term "Black River." He distinguished the "Birdseye limestone" and the "Isle La Motte marble" employing the latter term for a bed locally the main object of the quarrying industry, and known as the "Seven foot tier." Hall, in the first volume of the *Palaeontology of New York*, restricted the term Black River to this "Seven foot tier" and through his influence and the description of a very striking cephalopod fauna from the bed, the term "Black River" was quite generally accepted for the "Seven foot tier." Since, however, mainly through the investigations of Dr Ulrich, the fact has become apparent that beds which in the Mohawk valley and the Lake Champlain region have been referred to the Black River limestone, are both older and younger than the Black River as restricted by Hall, but fall within the limits of the original conception of Black River, it has become advisable to revive this original usage of the term to avoid confusion. The "Seven foot tier" or Black River limestone of Hall has then to be renamed and the term "Watertown" is here used for this formation [see p. 84].

¹ By R. Ruedemann.

Lowville limestone. The Lowville limestone which is the "Birdseye limestone" of the old Geological Survey reports has its maximum development in New York in the region of the lower Black river, or in the southern portion of the area here mapped. It reaches there about 60 feet in thickness. It consists typically of thick and thin bedded, fine grained dove limestone which shows a characteristic ashen gray weathering and contains either numerous more or less vertical worm tubes denoted as *Phytopsis* and filled with calcite (producing the "birdseyes." in sections) or shows in profusion the horizontally spreading tabulate coral *Tetradium cellulosum* and related species. Between these typical Lowville beds there are intercalated others of subcrystalline dark to black limestone, or of oolitic or also of shaly whitish weathering limestone. These intercalations usually contain a larger fauna than the dove limestone and carry lamellibranchs, gastropods and cephalopods, as well as ostracods and trilobites.

The basal bed is conglomeratic and of very variable thickness; it is overlain by several feet of strata that contain quartz grains or grit bands and are more or less shaly, the shaly limestone gradually becoming more massive upward and assuming the characters of the typical rock. These more or less sandy beds comprise about 4 feet.

The uppermost portion of the Lowville beds which has been mentioned by the earlier authors as the "cherty beds" has been found by Professor Cushing and the writer to be quite distinct from the typical Lowville beds and separated from them by an unconformity. It has for that reason been here distinguished as a subdivision under the name Leray limestone and will be described separately [*see below*].

It appears that in this region the Lowville beds beneath the Leray member can be conveniently divided into an upper and lower division of nearly equal thickness, the upper division alone containing the abundant *Tetradium cellulosum* and larger *Phytopsis*, as well as the typical massive dove limestone strata, while in the lower division more dark or black subcrystalline limestones containing only smaller forms of *Tetradium* and *Phytopsis* and more thin bedded dove limestones abound.

In this lower division also two or more horizons of *Stromatocrium* can be observed, which give the beds a very irregular concretionary appearance. These horizons are well seen in the railroad cut just south of Sanford Center, also where the road crosses

the southern branch of Horse creek on the Clayton quadrangle and best along the Black river just east of the boundary of the map. Such beds are seen in the lower third of the exposure on plate 19; other buncy surfaced layers also appear, with the depressions filled in with shaly material, which seem clearly due to rill action on tide flats.

While the sand grains which are found in greater or smaller number floating in the basal limestones indicate, if we may follow recent investigations, the conditions of quiet embayments, in which sands washed in from the land, drifted out into the bay and gradually sank to the bottom, becoming imbedded in the limestone mud, the following beds indicate that this sea became gradually deepened. The lower division still exhibits in the shaly beds the sun cracks and ripple-marks and numerous mud balls characteristic of mud flats while the upper beds in their more uniform, massive character contain the criteria of deposition farther off the coast line. It follows thence that the Lowville sea was an advancing sea in the area here mapped. From the development of the Lowville in the Mohawk valley and north of the Adirondacks, it can be inferred that this transgression took place from the southwest. In the Mohawk valley the distribution of the Lowville is very erratic, as fully discussed by Cushing in a former paper [Geology of the Northern Adirondack Region], it being entirely absent in some localities while in others it is connected by so called passage beds with the underlying Beekmantown. This erratic distribution is then clearly due to the irregularity of the surface over which the sea advanced, the Mohawk valley intersecting the deeply indented coast line of the Adirondack peninsula in Lowville time. In the Champlain basin at the base of the Black River group an outcrop of typical Lowville rock occurs in the Crown Point section. The bed referred to consists of 5 feet of dove limestone with *Phytopsis* tubes but otherwise apparently unfossiliferous. However, 12 feet above this dove limestone the writer found a large colony of *Tetradium cellulolum* together with *Orthoceras recticameratum*; another typical Lowville fossil, thereby clearly demonstrating the presence of the Lowville fauna in the Champlain basin.

Four species of fossils have to be considered as highly characteristic of the Lowville formation in the area here mapped, viz :

- Tetradium cellulolum* (Hall)
- Orthoceras multicameratum* (Emmons) Hall
- O. recticameratum* Hall
- Bathyurus extans* (Hall)

These species are not known to occur above or below the Lowville limestone, and are common enough to occur in every exposure of the formation.

Tetradium cellulosum forms large colonies, attaining sometimes a diameter of several feet (specimens of this size collected by the writer along Black river) and consisting of frequently dividing branches that radiate horizontally and obliquely upward from a common center. Its most characteristic aspect, however, is seen on sections where the squarish cells with their fission septa produce a neat lattice pattern. Different, hitherto undescribed species with looser arrangement of the polyparies or cells, occur in lower horizons.

Both *Orthoceras multicameratum* and *O. recticameratum* are easily recognized by the close arrangement of their septa and the latter form possesses in the angular course of the septa a character not shown by other species.

Bathyrus extans apparently occurs throughout the formation but is most frequent in several bands. It is, as Dr Ulrich informs us, preceded by closely related and very similar prenuncial forms in the Pamela formation.

On account of the but slight difference in the compactness of the rocks between the Lowville and Pamela formations, the former is not set off by an escarpment from the other, but both form one continuous plateau. In some districts the lower Lowville contains easily worked layers, furnishing subcubical blocks and the composition of the fences of such blocks is a quite characteristic aspect for this horizon.

Since the formation received its name from Lowville and a section of this type locality has not yet been furnished, we insert here the section, obtained at this place in the quarry at the railroad bridge over Mill creek, where in the creek bank the uppermost part of the Pamela (about 12 feet) is shown and a continuous section into the Leray limestone can be obtained. On account of the nearness of Lowville to the area here mapped, the Lowville section is to be considered as typical also for this area. For comparison we add the section measured in the Sanford cut which contains about three fourths of the formation. Another fine section was observed in the bank of the Black river above Watertown, opposite the filter plant, just outside the map limits, and a section of about 56 feet from the 7 foot tier downward is exposed in the high river bank opposite the Ontario Paper mill, 2 miles east of Brownville.

Unfortunately no good sections were found in the northwestern portion of the area, permitting a comparison with that of Lowville as to thickness and arrangement of horizons.

Section at railroad bridge at Lowville (type section)

Lowville section

- 6' Cherty beds. Dark blue, finely granular limestone, dirty white weathering. Columnaria horizon at base
- 1' 6" Bed full of horizontal worm tubes. Chert horizon at base
- 5' 9" Transitional bed from Leray to typical Lowville. In aspect like cherty beds with a few cherts, but contains also *Tetradium cellulosum*, besides *Leperditia fabulites*, *Rafinesquina minnesotensis*, and other brachiopods and bryozoans
- Base of Leray
- 3' Dove limestone, massive. *Phytopsis tubulosum* common near top; a few *Tetradium* cells
- 3' 1" Compact dark dove limestone, full of fossils (*Tetradium*, gastropods, lamellibranchs) and of crystalline calcite
- 4' 9" Thin bedded, dove limestone, full of *Tetradiums* (form with narrow, round tubes)
- 5" Dark, fine grained impure limestone with argillaceous streaks, containing a small *Monticulipora*
- 2' 4" Lighter, massive bed of dove limestone with few *Tetradiums*. Lowest 8 inches black, with thin seams of flint
- 4"-7" Stratum of granular, light gray limestone full of lamellibranchs and gastropods, their shells filled with calcite
- 1' 3" Black, massive, crystalline limestone, full of *Tetradium*
- 3' 4" Black to dark gray thin bedded dove limestone, containing a few *Phytopsis*
- 4" Same rock as above, but full of a narrow form of *Phytopsis*
- 4" Black, dove limestone stratum full of crystalline calcite
- 1' 7" Dark gray, granular limestone with many calcite crystals. Bottom of quarry
- 4' Dark gray, thin bedded, dove limestone, weathering shaly
- 4' Harder, argillaceous limestone
- 3' 10" Shaly dove limestone, varies much, very shaly in middle, full of sand grains, contains a few lamellibranchs
- 1' Hard, oolitic blue limestone, full of quartz grains and pebbles
- 6"-10" Shaly bed with seams of quartz grains or grit bands
- 0-3'+ Dark bluish gray limestone, full of pebbles, shale below. Very variable in thickness. Unconformity. Base of Lowville
- 1' 10" Gray and pinkish granular limestone, dove in parts
- 4" Thin bedded, shaly limestone, sand grains near top
- 1' 10" Dove, dark mottled, fine grained limestone, typical upper *Pamelia*
- 1' 7" Dove limestone with argillaceous reticulation, light pink in parts, weathering shaly
- 9" Bluish black flinty dove limestone
- 10" Gray, granular limestone with calcite and quartz grains, in parts conglomeratic, a few fossils. (*Rafinesquina incrassata*)
- 1' 5" Light dove limestone, somewhat argillaceous, coarsely laminated. *Phytopsis* on top
- 2' Grayish, bluish, blocky, subgranular limestone
- 1' Compact bed of harder, light bluish gray limestone
- 1'+ Dove, light gray limestone with crystalline specks

Sanford cut section

- 27' 2" Lowville
 1' 4" Blue gray, oolitic limestone, full of lamellibranchs and with
Tetradium cellulolum
 6' Massive *Tetradium* beds, dove limestone full of crystalline calcite
 5' Thin bedded, blocky dove limestone; second zone of *Bathyrurus extans*
 4' Irregular, thin bedded, blocky, dove limestone, more massive above, culminating in a heavy, irregularly surfaced *Stromatocerium* layer; holds *B. extans* below
 22"-14" Thin bedded, fossiliferous, dove limestone, with *Camartoechia plena*, fitting to uneven surface beneath
 16"-24" Heavy, massive dove limestone, *Tetradium* and other fossils, masses of *Stromatocerium* at surface, giving bunchy character
 4' 6" Speckly dove limestone with shaly seams; bryozoa, *Tetradium syringoporoides* (Ulrich, ms) and other fossils
 3' 2" Heavy, massive bed of gray, crystalline limestone, full of fossil fragments at base, bryozoa and gastropods above; conglomeratic, many quartz grains, base of Lowville
 1' 6" Shaly, dove, mud limestone, three beds; very fine, even grained, cherty looking

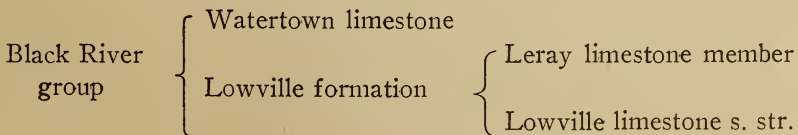
Leray and Watertown limestones. Emmons had already pointed out that the Seven foot tier was closely connected by its lithologic character with the underlying formation, and the writer had found, while in preceding years collecting the cephalopods of the formation, that the characteristic cephalopods of the "Black River" limestone for which the Watertown region is renowned among paleontologists, viz, *Gonioceras anceps*, *Hormoceras tenuifilum*, *Lituites undatus* and also the "Black River" coral *Columnaria ?halli* (= *C. alveolata* auct.) appear already below the Seven foot tier,¹ while at the same time the characteristic fossils of the Lowville cited above, especially also the omnipresent *Tetradium cellulolum*, disappeared. Since this faunistic extension downward of the "Black River" is coupled with a greater lithologic similarity of the uppermost 20 feet of the Lowville, as formerly conceived, with the "Black River" than with the typical Lowville, and this upper portion of the Lowville is characterized by seams of chert nodules which make good horizon markers, we decided to draw the Lowville-Black River line where *Tetradium cellulolum* abruptly disappears and the chert layers begin. In mapping the "Black River" on this basis, it was found that, on the whole, the cherty limestones also exhibit the characteristic blocky weathering of the Watertown bed,

¹ While these cephalopods first appear in greater number in the cherty beds just below the 7 foot tier, a few stragglers either identical or only pre-nuncial mutations of them, have already been noticed in much earlier horizons of the Lowville. Thus *Hormoceras tenuifilum* and a large colony of *Columnaria ?halli* were noted 11 feet below the cherty beds in a *Tetradium* bed in the section opposite the filter plant at Watertown.

and are a unity with them also in that, as a rule, they together form a distinct escarpment above the Lowville plateau. In some cases, however, the lowest 2 or 3 feet of the chert beds have remained clinging in very irregular patches to the underlying Lowville, thus forming the serpentine shaped outliers seen in the southern portion of the map.

The authors, under the necessity of drawing a definite boundary line between the "Black River" and Lowville limestones, which would meet the requirements of being lithologically and faunistically so well marked that it could be mapped with sufficient ease and precision, decided on uniting the cherty beds with the Seven foot tier, the two forming a physiographic and economical unit, as demonstrated by their being quarried together at Chaumont and other places. Dr Ulrich's investigations had shown him a more complete section in Kentucky from which it became apparent that the cherty beds are intimately connected there with the rest of the Lowville and that the unconformity observed in the Watertown region between the cherty beds and the other Lowville represents the hiatus which is filled in Kentucky and elsewhere by beds of transitional character, while on the other hand the cherty beds were found to be also separated by an unconformity from the overlying beds. Since, moreover, the "Seven foot tier" or Hall's "Black River limestone" is of but local importance, while the Lowville, including the cherty beds, is a most persistent unit over a very large area, it has been finally deemed preferable by the authors to disregard the local conditions of the Watertown region, and to retain the "cherty beds" limestone as a subdivision of the Lowville limestone, under the term "Leray¹ limestone," on account of the typical exposures in the town of Leray.

The following diagram indicates the relations of the beds as now understood by us:



Since a very irregular surface is observable between the uppermost tier of cherty beds, about 6 feet thick, and the underlying beds [*see* section of Klock's quarry, *postea* p. 90], and this bed contains the cephalopods more frequently than the other cherty beds, Dr

¹ Owing to an error of the printer this word was made to read Leroy on page 72 of Museum Bulletin 138.

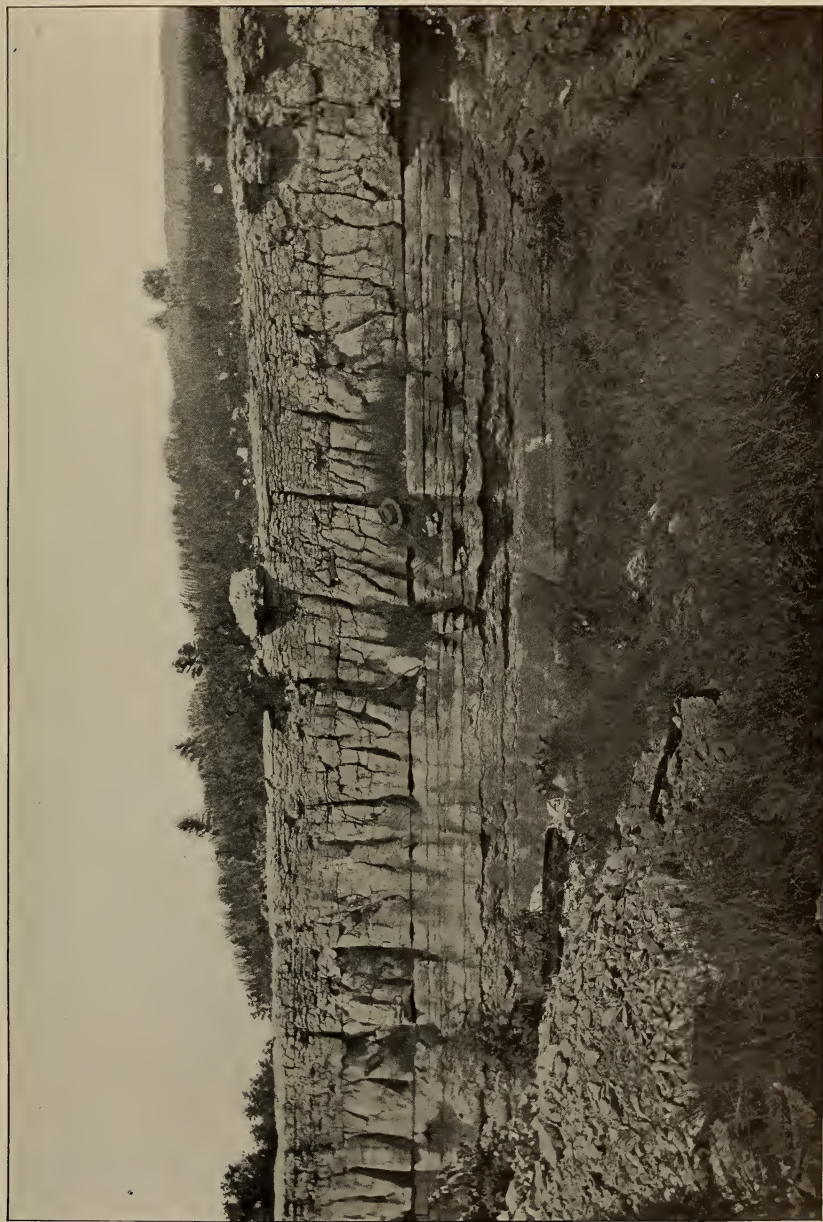
Ulrich is inclined to unite it with the Seven foot tier or Watertown limestone. We adopt here this view, leaving the final decision as to the exact boundaries to a future close study of the faunas involved, but consider the difficulty of an easy recognition of this boundary — located within a lithologic unit — in the field as another practical reason for mapping and discussing here the Leray and Watertown limestones together.

Finally, it was found in studying last summer, in company with Dr Ami, Professor Cushing and Dr Ulrich, the section at Klock's quarry at Watertown [*see* below p. 90], that there is properly referred to the Watertown also a bed $1\frac{1}{2}$ -2 feet thick, of black limestone, that still overlies the Seven foot tier.

With these upward and downward extensions of the formation, the limestone will be about 15 feet thick in its type region while the Leray limestone is about 13 feet thick, consisting of dark gray to black, heavily bedded, dove limestone, with layers of black chert nodules. The nodules are more or less scattered through the chert beds, forming here and there strings in the section and a distinct horizon over the whole mapped area near the base of the beds. Since large rock exposures of the surface of the Leray limestone are frequent in the region, one has often opportunity to observe large quantities of these cherts, half weathered out, on the rocks, presenting a flat, cakelike form. Some of the chert beds present, when weathered, a peculiarly fucoidal surface through intricate intermixing of the limestone with earthy films, and others are distinctly cross-striated.

The contrast between the massive chert beds and the thinner bedded underlying Lowville strata is well shown in plate 20. In natural exposures or where the quarry face is weathered, the Watertown and Leray formations are readily distinguished from the lower Lowville beds by their breaking up into small cubic blocks the size of a fist. The beginning of this breaking up, which is apparently due to a reticulate system of mud seams, is seen in plate 20 and farther progressed in plate 21. Here the rock is so weathered that it can be brought down with the pick and is of convenient size for road metal. It is also well shown on plate 19, where the hat lies just above the boundary line. This picture exhibits especially well the contrast between the evenly and thinner bedded typical Lowville limestone and the thick bedded blocky weathering Leray and Watertown beds.

In plate 22 will be found an excellent illustration of the unconformity between the Lowville and Leray limestones. The lower of



Leray limestone resting on upper Lowville in quarry at Threemile Bay station, Clayton sheet, looking north. Note the reef layer of *Stromatocentrum* midway in the Lowville. H. L. Fairchild, photo, 1908



Upper portion of the Lowville limestone with overlying lower Leray limestone, full of chert, showing its thick bedded character as compared with the underlying Lowville. Quarry 2 miles north-east of Watertown and near the south margin of the Theresa sheet. Shows also, on the right, a joint widened by solution, with thick turf-filling above. H. P. Cushing, photo, 1907

the two massive beds of Leray limestone which appear in the upper view is absent in most sections, as in plate 20, where the basal Leray bed is the equivalent of the upper bed of plate 22. In addition most of the Lowville shown in plate 22 is absent in other sections, the top Lowville bed in plate 20 being the equivalent of the basal bed of plate 22.

The Watertown limestone is a solid bank of dark bluish gray to black limestone, with rather indistinct bedding planes, very hard when fresh, showing numerous small calcite crystals (crinoid joints) and a fine reticulation from mud seams and many worm tubes. The mud seams or the earthy intergrowth causes the rock to break up most typically in small blocks.

When fresh the Leray and Watertown limestones, especially the Seven foot tier, furnish very large blocks. They are for this reason still extensively quarried at Chaumont where at present the immense blocks required for harbor improvements at Oswego and other cities along the Great Lakes are obtained.

The fact that the $1\frac{1}{2}$ -2 feet of black, knotty, impure limestone which overlie the Seven foot tier are separated by a very irregular contact from the overlying horizontally bedded Trenton, indicates that also this bed should be properly included in the Watertown formation.

The Seven foot tier and the just mentioned top bed of the Watertown formation owe their deep black color to the great amount of organic matter in the rock. This saturation with organic matter shows itself also in the presence of petroleum in the rock. In the large quarries at Chaumont endoceratites and other cephalopods have been found whose chambers were partly filled with petroleum and the writer was in a cellar in the hotel in Black River village above Watertown that is cut in the Watertown limestone and in which the petroleum is constantly oozing out of the cellar walls in such quantities that the floor is constantly covered with the oil and gallons of it are taken out for cleaning and oiling purposes. The top layer of the formation is especially strongly bituminous, and gives off a strong odor when struck with the hammer.

The upper beds of the Black River group of the neighborhood of Watertown have become world famous among paleontologists by the fine preservation and size of their cephalopods, some of which, notably *Gonioceras anceps*, have not been found elsewhere. It is essentially a cephalopod facies. The straight conchs of *Hormoceras tenuifilum* with their large pearly siphuncles, are especially common on the many ice-polished rock surfaces of the

region and on the rock shelves bordering the river. They are well known to the populace as "fish bones" which they indeed much resemble when broken through the middle. Also two species of large *Endoceras*, distinguished by Hall as *Endoceras longissimum* and *E. multitubulatum* are frequently seen to attain several feet in length and half a foot in diameter. *Gonioceras anceps*, readily recognized by its lyre-shaped septa, is rarer and *Lituites undatus*, another of the characteristic cephalopods of the formation is also less frequently observed. There is also a fairly large fauna of brachiopods and gastropods present, which, however, has been generally lost sight of since the fossils are hard of extraction in the massive rock and inconspicuous in comparison with the large cephalopods. This smaller fauna has not yet been described.

Physiographically the Leray and Watertown limestones form by far the most striking feature of the region. Their massiveness and hardness as compared with both the underlying typical Lowville limestone and the overlying shaly Trenton beds cause them to form a distinct plateau or terrace, rising with a frequently vertical escarpment from the Lowville exposure. This escarpment, however, does not present the straight face of the Helderberg cuesta but is deeply indented or composed of many parallel ridges separated by about equally wide valleys, and stretching in fingerlike groups for miles upon the Lowville plain. These fingers are especially well seen on the map northeast of Limerick, and west of Perch river. They rise abruptly from the Lowville plain while the intervalles rise more gradually to the level of the Watertown limestone plateau. The direction and form of these fingerlike erosion ridges and their relation to the prevalent direction of jointing in each special case suggest that they originated from ice plucking between especially deep and wide joints.

The Watertown limestone plateau is in comparison to the small thickness of the formation abnormally wide and the Watertown belt correspondingly broad on the geological map. This is due to the fact that the Trenton rocks are little compact and were easily swept off the massive Seven foot tier by the ice. The latter forms thus the surface rock over a very large area and is in many places swept clear of soil. This fact and the many deep joints make it a very poor underground for agricultural purposes, and the plateau is therefore frequently wooded, especially so the jagged and deeply jointed boundary region along the Lowville belt. Even small brooks have frequently formed deep solution and erosion ravines in this forma-



Leray limestone overlying Lowville, $2\frac{1}{2}$ miles northwest of Sanford Corners. The view illustrates the characteristic weathering of the Leray. Dr Ruedemann is at work on the upper surface of the Lowville. H. P. Cushing, photo, 1907



Upper view. Leray limestone overlying Lowville in quarry $1\frac{1}{2}$ miles south of Sanford Corners, looking south. A thickness of 9 feet of massive limestone of Leray character is shown, of which the upper half is equivalent to the basal cherty bed shown in plate 20, while the lower bed does not appear in that section. The Lowville shown beneath consists of beds which are higher than any in that section.

Lower view. Upper Lowville in quarry very near to that in the upper view, and showing the beds just beneath these there shown. The uppermost beds here shown are also absent in most sections, the Leray resting on some of the lower beds. H. M. Ami, photo, 1908

tion. One of the best examples of such a gorge is that of the Perch river at Limerick. Many brooks disappear entirely under the Watertown formation, forming long underground courses and caves. Several such courses are known in Watertown, where, however, they have been filled by the damming up of the river. Others are known below Watertown and at Black River village.

Phenomena entirely peculiar to this formation in the region are the inliers at the Natural bridge and Limerick. A glance at the Watertown-Leray belt on the Clayton sheet north and east of Chaumont bay reveals the fact that in several places the typical Lowville beds appear from beneath the Watertown-Leray limestones. These inliers consist of elongate strips of Lowville limestone exposed along brooks and surrounded on all sides by the Watertown-Leray limestones. The conditions which have produced this peculiar and rare form of inlier are the following: The coincidence of the dip of the beds and of the course of the brook and the greater resistance of the underlying Lowville limestone to solution. The brook as a rule reaches the inlier by a fall, and finally leaves it again by very gradually passing again upon the overlying rock.

A very characteristic example of such an inlier is seen along Threemile creek and a very large one at the head of Guffin bay. The most interesting of all is that below the village of Limerick on Perch river. It begins with the fall shown on plate 23 and ends above the Natural bridge. At the latter place the river passes underground through a ridge of Watertown-Leray rocks crossing the valley. Below the bridge the river reappears for a short distance [pl. 38] and disappears again, its course being thence traceable as a depression between the cliffs of Watertown-Leray rocks on both sides. The depression shows in the different tilting of the huge blocks of the Seven foot tier that it is the result of a gradual sinking down of the whole mass; and this indicates that the river, which has its underground course on the top of the typical Lowville beds, is dissolving the Watertown-Leray beds along its course from the base upward. There is little doubt that also the inlier above the Natural bridge, which can not have been produced by normal corrasion, is the result of solution of the Watertown-Leray beds, and that finally also between the Natural bridge and the lake the typical Lowville beds will be exposed and the river flow again overground, as it already does just below the bridge.

One of the best exposures of the Watertown-Leray beds is that at Klock's quarry, at the end of Huntington street at Watertown. This section which is here inserted, begins close to the base of the

Leray limestone and reaches to the base of the Trenton. The contact with the typical Lowville beds is shown on the opposite side of the river and on Diamond island. Plate 24 shows a part of the quarry.

Section at Klock's quarry, Watertown

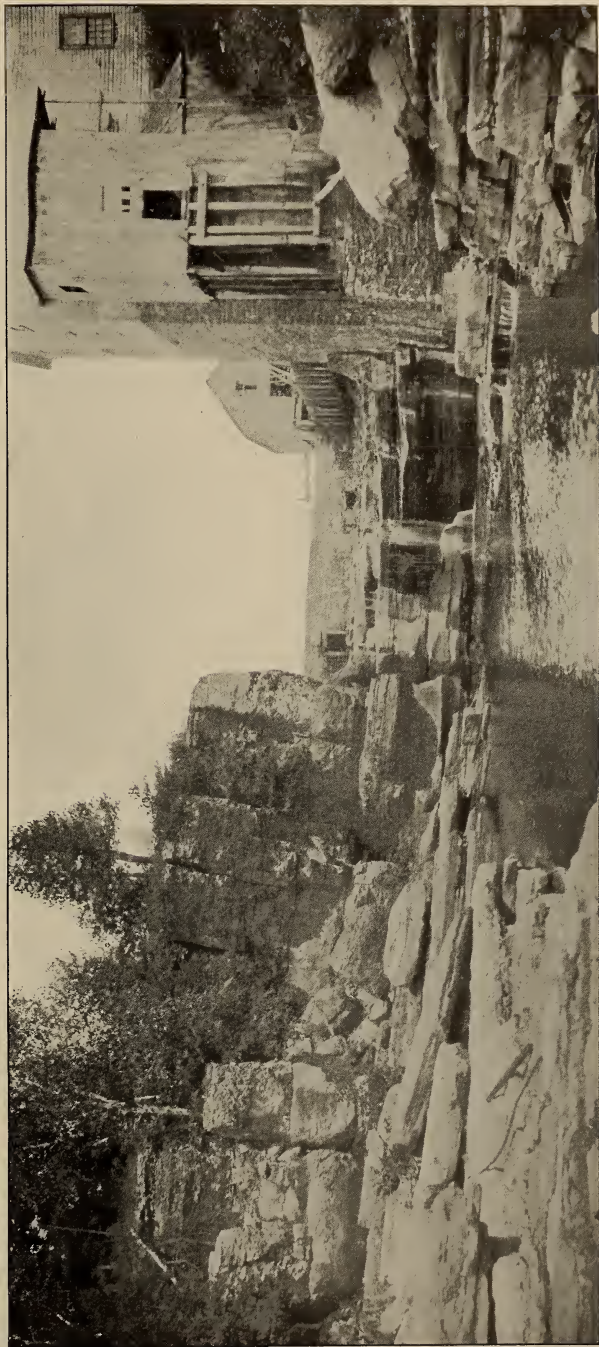
1½'-2'	Black, knotty, impure, dark limestone with <i>Strophomena filitexta</i> , <i>Leperditia fabulites</i> , <i>Orthis pervetus</i> , <i>Isotelus platycephalus</i> , <i>Orthis tricenaria</i> , <i>Iliaenus americanus</i> , etc.
7'	7 foot tier. Heavy black limestone, with <i>Gonioceras anceps</i> , <i>Hormoceras tenuifilum</i>
6'	Dark gray to black, heavily bedded, cross-striated limestone with a few cherts, containing also <i>Endoceras</i> , <i>Gonioceras</i> . Resting on an irregular surface; base of Watertown limestone
2'-2½"	Irregularly bedded, dark to black, dove colored, fine grained limestone, characterized by weathered, furoid, earthy markings
5'+	Fine grained dark gray limestone, with cherty layer on top. Cherty beds. Bottom not shown

These chert beds are in this neighborhood underlain by 4-5 feet of fine grained dark gray beds with *Tetradium cellulosum*, which also weather blocky like the Watertown limestone. Below this are found the dove colored, thinner bedded, typical *Tetradium* beds.

A series of good sections of the Watertown-Leray limestone are exposed in the large quarries about Chaumont. Since, however, the Seven foot tier forms here the top of the section and an unknown thickness of the same is always eroded, the thicknesses obtained are always a minimum. In the large quarries at the head of Chaumont bay the combined beds measure 18 feet; in the big quarries along Chaumont river 19 feet of these limestones are found, below which 22 feet of typical Lowville beds are exposed to the river edge.

Trenton limestone. The last of the Lower Siluric stages occurring in the area of the map is the Trenton limestone. It appears first in outliers near the mouth of Black river, then occupies the southern portions of the peninsulas jutting out into Lake Ontario and finally on the Cape Vincent sheet forms a continuous belt. In contrast to the underlying formations and notably its direct predecessor, the Watertown limestone, which forms a remarkably level plateau with a distinct escarpment at the northern boundary, the Trenton appears in well rounded hills, its boundaries approach subcircular curves, in contrast to the many fingered and deeply indented Watertown exposures. This is due to the fact that the Trenton is a much thicker and at the same time a much less resistant formation, consisting almost entirely of thin bedded limestones with shaly intercalations. It is therefore also much more covered by drift and as a rule exposed only along the shore line or

Plate 23



Falls of Perch river at Limerick, Clayton quadrangle; cliffs of Leray limestone overlying Lowville. E. O. Ulrich, photo, 1908



Upper view. Watertown limestone near river at Watertown, showing seven foot tier and the upper portion of the cherty bed beneath.

Lower view. Trenton limestone in creek bank near Threemile Bay, Clayton quadrangle. A closer and more detailed view of part of the section shown in plate 25. E. O. Ulrich, photo, 1908

on the *stoss-seite* of the hills. But since the thin limestone slabs over the Trenton belt have been incorporated in great quantities into the drift, whence they have found their way into the stone fences, these stone fences composed of thin Trenton slabs are almost the most characteristic feature of the Trenton formation in the district and they are remarkably closely bound to the present distribution of the Trenton.

The contact between the Black River and Trenton groups is but rarely seen, but where found, it indicates an unconformity, either by the irregularity of the contact line, as at the Klock quarry at Watertown, or by the presence of a basal conglomerate bed in the Trenton as at Threemile Bay.

The best continuous exposure, or in fact the only good one within the boundaries of the mapped area, is that found along a brook at the western outskirts of the village of Threemile Bay [pl. 24, 25]. This section is given below. Another fairly complete section can be obtained from Klock's quarry to the top of Pinnacle hill at Watertown and a third, which however lacks the base, at the west end of Carleton island in the St Lawrence river.

Section of lower Trenton limestone at Threemile Bay

(generalized)

16'-17'	Fine grained thin bedded limestone with shaly intercalations
3'	Thin bedded limestone layers with shaly intercalations, rich in lamellibranchs, gastropods and cephalopods
10'	Fine grained black limestone with shaly partings, in part barren, in part full of fossils on shaly partitions, mostly large conical or hemispheric bryozoans (<i>Prasopora simulatrix</i>) in horizon about 2 feet from base
3' 6"	Black, fine grained limestone full of worm tubes, no other fossils
5' 6"	Gray, crystalline, thin bedded limestone with many crinoid joints on top (2 feet) and fine grained dark thin bedded limestone below, with shaly intercalations. The limestone beds full of brachiopods (<i>Dalmanella</i> , <i>Rafinesquina</i>) and bryozoans
6'	Dark gray to black compact limestone, in strata 1 foot thick with thin shaly partings. Very fossiliferous. <i>Dalmanella testudinaria</i> , <i>Plectambonites sericeus</i> , <i>Calymene</i> , bryozoans (<i>Pachydictya acuta</i>) and crinoid joints
5"	Conglomerate bed with crystalline matrix and crinoid joints
	Base of Trenton
.....	Black River beds

It follows from this and the other sections that the Trenton begins with a thin conglomeratic bed, on which rest about 6 feet of dark gray to black compact limestone, in beds about 1 foot thick, with thin shaly partings. The latter are very fossiliferous, containing most profusely *Dalmanella testudinaria*, *Plectambonites sericeus*, *Pachydictya acuta* and crinoid joints.

This black basal limestone of the Trenton contrasts strongly with the equally thick underlying Seven foot tier in being a most inconspicuous element in the physiography of the region. In fact its presence is hardly suspected over the greater part of the area, since it is nearly always hidden at the base of the rounded Trenton hills. Only where the formations are planed to one level, as about Rosière, is it observed to outcrop as a recognizable belt.

The remainder of the Trenton, as far as the area of the map is concerned, consists then of about 50-60 feet of thin slabby limestones, with shaly intercalations. The limestones are partly gray and crystalline with many crinoid joints and partly fine grained, dark gray to black. The latter limestone swells sometimes into thicker beds (1 foot thick and more) of black limestone which is either quite barren of fossils save worm tubes, or as on Carleton island, almost entirely composed of the shells of *Plectambonites sericeus*.

Plate 25 shows the general aspect of the thin bedded limestones in the creek bed at Threemile Bay and plate 24 which gives a closer view of the rocks in the same locality, illustrates the regular alternations of limestones and shales in the formation.

The greater middle and upper part of the Trenton is found in the region south of the map, on the other side of Black River bay.

The fauna of the Trenton has the general aspect of that of the formation in other parts of the State. Its details have not yet been studied.

SUMMARY OF PALEOZOIC OSCILLATIONS OF LEVEL¹

It has been shown that the Potsdam and Theresa formations were deposited in the west end of a sagging basin or trough which occupied the general line of the present St Lawrence valley; that the deposition began at the east and worked westward, involving our region here only in its later stage; and that the depressed trough was a westward extension from a similar subsiding trough along the Champlain valley line. There the Potsdam is very thick, is followed by beds similar to those here called Theresa, and these are overlaid by nearly 400 feet of dolomites which have been heretofore classed with the Beekmantown formation, as Division A of that formation. No such beds as these last appear in our district here, though the Potsdam and Theresa may be equivalent to them in time. In the Champlain valley also appear four other divisions of the Beekmantown, with an aggregate thickness in the neighborhood of 1400 feet.

¹ By H. P. Cushing.



Thin bedded limestones of lower Trenton age in creek bed at Threemile Bay, Clayton quadrangle, looking northwesterly, upstream. H. P. Cushing, photo, 1908

Ulrich has recently made the important discovery of an unconformity between these beds and Division A, and we coincide in believing that this division is properly to be classed with the beds below rather than with the Beekmantown. The Beekmantown that is thinly present in the district here reported upon is not of the Champlain type, but of the Mohawk valley type, lithologically and faunally quite like the beds at Little Falls and thence eastward through the Mohawk valley, which have heretofore been called the "fucoidal beds," and which we are proposing to call the Tribes Hill formation. This Beekmantown did not come into this northern district from the east but from the south, and so far as we know did not extend on eastward. But in passing to the eastward, beyond the limits of the region here mapped, Beekmantown beds begin to appear above the Theresa, and in our belief are unconformable, though this has not yet been demonstrated. Also in our belief this Beekmantown is not representative of the lower portion of the formation but of the upper portion; and we must go yet farther east to find the lower beds coming in; while the thin edge of Tribes Hill Beekmantown in our district here is lowest Beekmantown. Following a condition of uplift Beekmantown submergence seems to have commenced fairly simultaneously on the east, west and south sides of the Adirondack region. Submergence on the west was quickly followed by emergence due to a general eastward tilting of the region, so that at Little Falls and about Theresa only a slight thickness of the very lowest Beekmantown was laid down, the Tribes Hill formation. This formation steadily thickens to the eastward, along the Mohawk valley, though apparently representing nothing but the lowermost Beekmantown. The chief area of Beekmantown sedimentation in New York was the Champlain valley trough and its prolongation southward. Along with the steady subsidence in that trough seems to have gone a subsidence of the St Lawrence trough which, like the previous Potsdam subsidence, seems to have commenced at the east and worked westward; so that, in that trough, the lowest Beekmantown is absent, and steadily higher beds are at the base going west. The extreme westward reach of this Beekmantown depression of the St Lawrence trough seems never to have reached the Theresa district, where the only Beekmantown represented is the thin base of the Tribes Hill formation of the Mohawk Beekmantown type. Until the Beekmantown on the north side of the Adirondacks has received more thorough study, this view of Beekmantown conditions in the St Lawrence trough can not be regarded as based on sufficient evidence, though evidence on the other three sides of the Adirondack region

in respect to these conditions seems now quite well substantiated. Our immediate district in late Cambrian (Ozarkian) time sloped to the east and received the thin deposit of Potsdam and Theresa beds laid down in the western end of the St Lawrence trough. Uplift followed throughout New York, producing unconformity between these beds and those of the Beekmantown which follow. Beekmantown subsidence seems to have commenced simultaneously on the east, west and south sides of the Adirondacks, with a tilting of the surface in our district here, so that its slope was to the southwest, instead of to the east. This was quickly followed by tilting of the whole region to the east, stopping Beekmantown deposit on the west and south sides of the Adirondacks and confining it to the eastern trough. From this trough a bay seems to have developed westward up the St Lawrence trough, during Beekmantown time. The Beekmantown was brought to a close by another uplift of the entire northern New York region. In the Theresa district this time gap was a long one during which 1000 feet or more of Beekmantown rocks were deposited in the Champlain trough, and a much greater thickness in other regions.

Through these early times then our district had a general slope of its surface toward the east, though with an intervening time of short duration during which the slope was to the southwest. There were three depressions, alternating with three elevations of the surface, though apparently the deposits of the third depression just failed to reach the district.

In the Champlain valley the Beekmantown is succeeded by the Chazy limestone formation, the two being separated by a slight unconformity, indicating that the Beekmantown was followed, as it had been preceded, by general uplift of the whole area. Depression was then renewed in that trough for the third time, and for the third time a bay was developed westward from it. This Chazy bay, however, seems not to have reached as far westward as the preceding Beekmantown bay, and certainly fell many miles short of reaching our district here.

The Champlain Chazy is divided into lower, middle and upper subdivisions. The typical Chazy rocks are limited to the Champlain trough and its prolongation north and south. This trough was separated from a much larger depressed area to the westward, by a land barrier, which prevented the passage of organisms from the one basin to the other. At the same time therefore in which the Chazy rocks were being deposited in the Champlain trough, other deposits, characterized by a different fauna, were forming to the west of them,

and the rocks of this group are known as the Stones River formation. During Chazy time the depression in which Stones River rocks were forming was encroaching upon northern New York from the south and west, and by the close of the middle Chazy this depression had become sufficiently extensive to involve our district here, and the deposition of the Pamela formation commenced, the Pamela being the local New York facies of the Stones River formation, and representing only a portion of its upper division. The tilting of our district necessary to permit of this invasion from the southwest, changed its former easterly inclination to a southwesterly one, over most of the district; but apparently this change of slope died out on the eastern edge of the Alexandria sheet, east of which lay the land area which separated the Pamela basin from the Chazy basin; and this received no westerly tilt, but chiefly retained its old slope to the east. This in our view is the origin of the Frontenac axis, as the narrow isthmus of Precambrian rocks which connects the main Adirondack Precambrian mass with the great Canadian area of these rocks, and which passes through our district here, is called. It simply represents an axis of the old Precambrian floor which became less depressed than the portions of the floor east and west from it. The Potsdam-Beekmantown-Chazy depressions sagged the district to the east, covering it with steadily increasing thickness of their deposits in that direction; the Pamela depression sagged the district to the west, and in that direction the overlying deposits steadily increase in thickness. The Frontenac axis is the pivotal district between the two, where sagging was least and deposit thinnest. Subsequent erosion could thus wear away this thin cover and bring the Precambrian back to daylight, along this line, as it has done, while yet the thicker cover, east and west, in part remains.

According to Ulrich the Pamela formation is of age intermediate between the middle and upper Chazy of the Champlain valley, but little sedimentation having taken place there in Pamela time; in other words while this region was subsiding and accumulating deposit, that ceased to subside. With the cessation of Pamela deposition on the west, resulting in the unconformity between the Pamela and Lowville, deposition was renewed on the east and the upper Chazy was laid down. In like manner the Lowville formation is but slightly represented in the Champlain valley, though well developed here, as if, with renewed subsidence here it again ceased there. Toward the close of the Lowville, uplift occurred on the northwest giving rise to the unconformity between the main mass of the Lowville and the Leray limestone. At the same time depression

began in the Champlain region, and what has there been called Black River limestone commenced its accumulation. This deposit consists of a small thickness of typical Lowville at the base, the equivalent of the Leray limestone at the summit, and intermediate beds which represent the Lowville-Leray hiatus of the northwest; while the Watertown limestone is lacking. With our suggested nomenclature this may still be properly called Black River, while on any other arrangement it could not be so called. The Mohawk region was close to the shore line throughout Black River time and received only the very thin, near-shore edge of the deposits of the group, never more than a few feet thick, often practically absent and varying much in horizon from place to place.

At the close of the Leray, uplift was widespread and the Watertown limestone is practically absent except in that locality, in strong contrast with the widespread occurrence of the preceding Leray. Then followed subsidence on the east with accumulation of the Amsterdam limestone, which is wholly absent on the west. Then ensued on all sides of the region the Trenton submergence; limestone quickly followed by black shale on the east so that the bulk of the eastern Trenton is of shale; the shale gradually encroaching westward, but the western Trenton, of the type locality and northward, remaining of limestone throughout. The black shale of the Utica followed, with northern New York more largely submerged than at any other period in its geologic history, the Grenville possibly excepted. Possibly the Adirondack island was entirely submerged. With the close of the Utica local elevations began to appear, and by the close of the Ordovician much of the State was again unsubmerged. Since then most of northern New York has remained a land area. The appended chart will, it is hoped, aid in the understanding of these views.

Trenton group	Watertown region Utica shale Trenton limestone	Trenton Falls Utica shale Trenton limestone	Mohawk valley Utica shale Dolgeville shale Trenton limestone	Saratoga vicinity Utica shale Trenton shales Amsterdam limestone	Champlain valley Utica shale Cumberland Head shale Trenton limestone				
Black River group	Watertown limestone Leray limestone Lowville limestone	Leray limestone Lowville limestone	Amsterdam limestone Lowville limestone	Amsterdam limestone	Amsterdam limestone Black River limestone				
Chazy group	Pamela limestone				Valcour limestone				
Beekmantown group	Tribes Hill limestone	Little Falls dolomite	Tribes Hill limestone Little Falls dolomite	Little Falls dolomite Hoyt limestone	Crown Point limestone Day Point limestone Division C, D and E of the Beekmantown Tribes Hill limestone (?) Little Falls dolomite				
Saratogan	Theresa formation Potsdam sandstone			Theresa formation Potsdam sandstone.	Theresa formation Potsdam sandstone				

NOTE.— Parallel lines represent the greater, and dotted lines the lesser unconformities. Unbroken lines represent absence of breaks.

Dip of the Paleozoic rocks

It has just been stated that the Paleozoic rocks dip away from the Frontenac axis in both directions, and it is desirable to scrutinize the matter somewhat more closely.

In the southeastern corner of the Theresa quadrangle the base of the Leray limestone is at 600 feet altitude. The general line of outcrop of the formation runs across the mapped area in a west-northwest direction, and on the Cape Vincent sheet passes beneath the river level 247 feet. This is a drop in altitude of 353 feet in 27 miles, about 13 feet to the mile, in this west-northwest direction. In the direction of due west it is about 16 feet per mile, as nearly as can be calculated. Neither one of these, however, gives the direction of true dip, which lies somewhere between s. 30° w. and s. 45° w. At Adams, which lies some 30 miles somewhat west of south of the village of Theresa, three deep wells were drilled for gas some years ago, and the records of these wells are given by Orton.¹ Fairchild, who is familiar with the region, has also supplied me with data. Starting on ground whose altitude is approximately 600 feet above sea level, these wells reached the Precambric at depths of 915, 950 and 960 feet respectively. The Precambric surface is here approximately 315 feet below sea level, while at Theresa it averages about 400 feet above the sea. In the 30 miles then, this surface drops 715 feet, or nearly 24 feet to the mile. This however is the slope of the Precambric surface, which may or may not coincide with the dip, and in all probability does not. If the different limestones could be distinguished in the well records the data would be at hand for determining the dip, but this is unfortunately not the case. If the Paleozoic rocks thicken in that direction, the dip is somewhat less than the above figure; if they thin it is somewhat greater. At Adams the Potsdam and Theresa formations, 150 feet in thickness about Theresa, have disappeared. The other formations are present however and are unquestionably thicker than at Theresa. Beginning near the summit of the Trenton, the drill at Adams penetrated through 900 feet of limestone before reaching the Precambric. If we knew the thickness of the Trenton in our district here we should again have the necessary data, but all the upper Trenton lies to the south of the map limits, and the thickness of the formation has never been accurately measured so far as we know. It is certainly as much as 500 feet and may be a hundred feet more than that. We have then at least 800 feet of Paleozoic rocks here below the Utica, and perhaps 900. It seems therefore that the thickening of the upper

¹ N. Y. State Mus. Bul. 30, p. 457-58.

limestones at Adams just about compensates for the disappearance of the Potsdam and Theresa formations there, and that the dip is substantially the same as the fall of the rock floor, or 24 feet per mile. At most there is a deduction of but 100 feet to be made, amounting to 3 feet a mile in 30 miles, and reducing the total to 21 feet per mile. If, as is likely, this is still not the direction of true dip, being too nearly due south, the figure must be somewhat enlarged, and in all likelihood it amounts to from 25 to 30 feet per mile, certainly not exceeding 35 feet.

It is of interest to note that this dip, and this slope of the Precambrian floor, are much less than those worked out in the upper Mohawk valley by Miller and myself (Remsen and Little Falls quadrangles) where the dips approach 100 feet per mile to the southwest, and the Precambrian floor underneath has a slope exceeding that of the dip by some 30 feet. The matter of the present dips is simply the sum total of tipping given to the rocks since they were deposited, by the various oscillatory movements to which each region has been subjected since; showing that the Mohawk rocks have been somewhat more tipped than those here. The matter of floor slope however shows clearly that the shore line in the Mohawk region had a somewhat greater cant than was the case here, producing more rapid overlap of the rocks there.

In the northeast portion of the Alexandria sheet the dip has flattened out to practical horizontality, Potsdam with overlying Theresa forming the river bluffs. Going east, down the river, the dip soon changes to the northeast, carrying these formations beneath the water and the westerly edge of the Beekmantown becomes the surface rock, beyond which, for many miles, the river flows through Beekmantown rocks, all with slight northerly dip. These are the deposits of the eastern basin, and received no tilt to the west.

ROCK STRUCTURES¹

Foliation

Foliation is the name applied to the species of cleavage developed in rocks which, under compression, have wholly or largely recrystallized. The cleavage is chiefly due to the arrangement which the compression enforces on many of the recrystallizing minerals, which tend to develop in the shape of

¹ By H. P. Cushing.

leaves or needles; so that, in so far as the mineral particles have longer diameters, or scalelike shapes, these develop in the planes at right angles to the direction of compression and give the rock a tendency to split along them. Obviously a better cleavage will usually develop in rocks which consist of more than one mineral than in those composed chiefly of a single one, and in the former case a better cleavage will appear where there is large difference in the characters of the different mineral species than where this difference is small. Thus a quartz-mica rock, or a feldspar-hornblende rock, will be apt to have a much better foliation than a quartz-feldspar rock.

A rock in which a good foliation cleavage is developed, so that it tends to split rather evenly and readily is said to be schistose, or called a schist. When the foliation is less even, and less ready, gneissoid is the adjective, and gneiss the substantive employed. As a general rule certain sediments, such as shales and impure (or shaly) limestones and sandstones, recrystallize into schists, while pure sandstones and limestones, which recrystallize into pure quartz or pure calcite rocks, and consist chiefly of the one mineral, show little or no foliation. Igneous rocks are usually already crystalline, and in general do not recrystallize with as prominent a foliation as do many of the sediments, hence are more prone to form gneisses than schists.

Foliation in the Grenville rocks. The pure Grenville quartzites and limestones are now quite massive crystalline rocks with little or no foliation, though there is some development of fracture cleavage in the resistant quartzites, which is lacking in the more plastic limestones. Even the quite impure limestones show usually but little foliation. The impure quartzites have developed either pyroxene or mica on recrystallizing, usually the former, and this rock has poor cleavage while the latter become quartz schists. In the mass of Grenville rocks of varying composition to which the general name of the "schist series" has been applied, foliation cleavage is in general prominent. But even here rocks with considerable development of minerals of the mica type are relatively rare, and since such constitute the most prominently foliated rocks, their rarity militates against the prominence of foliation in the series, the bulk of which would be better classed as gneissoid, rather than as schistose. Some varieties of the amphibolites are quite micaceous and hence possess good foliation cleavage. The green schists and ordinary amphibolites usually show fair foliation only, and a general assemblage

of all the types of Grenville rocks of the district does not give the impression of a group of extra well foliated rocks. This is largely due to the comparative scarcity of micas, and of amphiboles of slender habit, in the series and the abundance of pyroxenes and of stout amphiboles. This again is a result of the prominently anamorphic character of the metamorphism.

The foliation of the Grenville rocks is parallel to the bedding. In the schist series rapid alternations of materials of somewhat varying composition is a feature, producing a very well banded structure, sometimes so fine as to somewhat mimic a coarse foliation.

Foliation of the granite gneiss. It has been shown that the Laurentian granite is characterized by frequent inclusions of older rocks, chiefly of amphibolitic types, and that there is also present much intermediate material, resulting from the soaking of the amphibolite with granitic substance, or from its actual digestion by the granite. The rock itself contains normally some mica or hornblende, and hence, through the greater portion of the mass these minerals are present in varying quantity, and the rock is susceptible of foliation development under the proper conditions. That such conditions have obtained is clearly shown, a foliation cleavage of varying prominence appearing nearly everywhere, though it becomes very obscure in those relatively small portions of the mass which consist solely of quartz and feldspar. The general rock is thus foliated but with foliation of the crude type which proclaims the rock a gneiss, rather than a schist.

The foliation structure of the granite gneiss conforms everywhere in dip and strike to that of the adjacent Grenville rocks. While this by no means excludes the possibility that the Grenville rocks may have been compressed and foliated prior to the intrusion of the granite, it does demonstrate that both sets of rocks have undergone compression in common, subsequent to this intrusion. It is quite possible that much of this compression was a result of the actual intrusion, and that the granite gneiss actually solidified with a foliated structure. This is not at all uncommon in great bathylithic intrusions, which, in order to make a place for themselves, must endeavor to shoulder aside the rocks previously occupying the space. This shouldering pressure exerted on the adjacent rocks under bathylithic, or deep seated, conditions, that is with a thick cover of overlying rocks, tends to give the rocks thus compressed a foliation which parallels the

margins of the bathylith, and hence boxes the compass in direction. At the same time the rock of the bathylith, while solidifying, may develop a similar and parallel foliation.

While it can not be affirmed that such results were not brought about in the region, it can be positively stated that, if so, they have been so disguised by subsequent compressive stresses that the effects of the two can not now be successfully disentangled. This is shown in several ways: (*a*) the microscopic study of the granite gneiss indicates that, to a considerable extent at least, its foliation is due to recrystallization rather than to original crystallization, in other words the rock has been much crushed and somewhat recrystallized under compressive stress, since it originally congealed; (*b*) these later stresses seem to have been severe enough to materially change the shape of the bathylithic masses, elongating them greatly in the northeast-southwest direction and correspondingly pinching them together in the direction at right angles to this; (*c*) instead of the foliation running around the bathyliths, with parallelism to the margin, it retains its general northeast-southwest strike throughout the region, independently of these margins, so that either no such marginal foliation was ever developed, or else it has been practically eliminated by the subsequent compression; (*d*) later igneous rocks than the granite gneiss have also had a foliation developed as a result of compression, most prominently in the earlier ones, and with steady decrease in prominence in the later.

It thus appears most probable that the general parallelism of the foliation of all the Precambrian rocks, and its substantial uniformity in direction throughout the region, is chiefly owing to compression of later date than that of the Laurentian granite intrusion. This appears increasingly true in going eastward into, and across, the Adirondack region. The rocks show steady increase in amount of metamorphism, in degree of mashing and recrystallization, in uniformity of foliation, and in obliteration of such possible structures as primary foliation. Some of this increase may be ascribable to greater thickness of cover, but the evidence of thoroughgoing compression of much later date than the Laurentian, is very clear.

Foliation of the later igneous rocks. The Alexandria and Theresa syenites seem closest to the Laurentian in age, among the conspicuous igneous rocks of the district. The Alexandria syenite shows cores of fairly massive rock, not foliated though with a considerable amount of crushing. But the porphyritic

border phase is considerably metamorphosed and converted into a thorough gneiss, with the augen (the uncrushed remnants of original large feldspar crystals) alined in the direction of the foliation. This also is coincident with the direction of foliation in the Grenville and Laurentian rocks. While it is true that the metamorphism exhibited by the syenite is not as severe in degree as that shown by the other two groups, it is clear that there was severe compression of the region at, or after, the time of syenite intrusion, and compression under quite similar conditions as regards overlying load.

The Theresa syenite does not appear so foliated as does the Alexandria, chiefly because of difference in composition, which shows itself mineralogically in the much slighter development of hornblende and mica, the rock consisting largely of feldspar. It also lacks the coarsely porphyritic phase. Foliation is therefore much less prominent, though the rock shows crushing and recrystallization in degree quite comparable with the other. It has therefore likely experienced compression of substantially equivalent amount and duration, but its composition prohibits good foliation development.

Picton granite. This, the latest of the early intrusives of the district, shows little or no foliation, and to the eye gives little evidence of crushing, as if the intrusion was wholly subsequent to the great squeezing of the region. The thin sections bear out this impression.

This evidence would seem to indicate compressive stresses applied at intervals through a considerable length of time during the region's very early history, with gradual cessation, and that the foliation structure in the Grenville and Laurentian rocks must be due to something more than the pressure and heat furnished by the intrusion of the Laurentian granites.

Joints

The clean-cut divisional planes, usually highly inclined, which occur in most rocks, are termed joints. While generally vertical, or nearly so, they may have any inclination. In a "joint set" the divisional planes show a close approach to parallelism, both in trend and in inclination. In most regions more than one set is present. When there are two, the usual condition is that they are approximately at right angles to one another. Often there are more than two sets as is the case in our region here. When four sets are present it is usually found that they are separable

into two pairs, each pair consisting of two joint sets at right angles to one another, and the joints of one pair bisecting the angles between the joints of the other pair. In such districts it is seldom the case that all four joint sets are exhibited in a single rock exposure, two or perhaps three of the four showing, rather than the whole number. In many, if not in most, regions where four or more joint sets occur, it is found that one pair tends to north-south and east-west directions, with another pair showing northeast and northwest trends. The joint planes often curve somewhat, so that the compass direction of a given set may vary through a considerable number of degrees. This tendency much increases the difficulty of discrimination between the different sets in districts where more than four are present, as is quite frequently the case.

In folded rocks the character of the jointing differs considerably from that found in rocks not folded. Since in our region here we have rock masses of each sort, Precambrian rocks which have been greatly compressed and folded, and overlying Paleozoic rocks which are comparatively undisturbed, it will be convenient to consider them separately.

In the Precambrian rocks. The diagram [fig. 5] presents a summation of the readings taken on the joints of the Precambrian rocks of the district included in the maps. They are comparatively few in number, partly because of the comparatively small area which presents these rocks at the surface, and partly because the joints were found to be so irregular that no satisfactory readings could be obtained in many exposures. The rocks are not as abundantly jointed, nor are the joints as clear-cut as usual in the Adirondack region.

In closely folded sediments, such as the Grenville, joints are apt to be present as a result of compression, and to have their directions controlled to a considerable extent by the folds, or in other words by the strike and dip of the folded sediments. These have been shown to have a general northeast strike throughout the district, though locally varying in direction through more than 90° . The more usual direction however is n. 40° e.--n. 60° e. Two sets of joints are present which have the same surface trend, that of the rock strike, the one set controlled by the dip and having approximately the same inclination, the other inclined in the opposite direction, or to the southwest, and closely at right angles to the first

set. Figure 4 is an attempt to illustrate these relations. These two joint sets, both having the same strike as the Grenville rocks, are much the most prominent of the joints which these rocks show, and

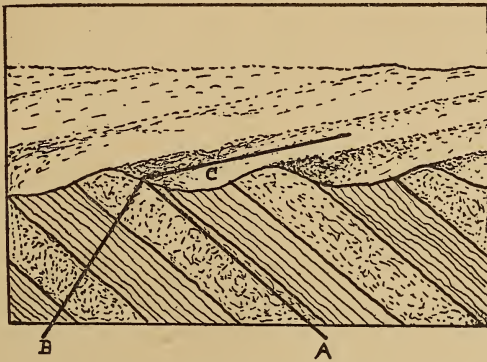


Fig. 4 Sketch and section of alternating quartzite and amphibolite bands of Grenville series, the quartzites forming low ridges on the surface. The line A represents the direction of the joints which follow the dip, the line B that of those at right angles to the first set, and C represents the direction in which both sets cut the surface

conspicuous at every good exposure of the Grenville schists or quartzites, though much less conspicuous in the limestones. The quarry face in plate 2 is on the dip joints, here steep, and the other set are quite flat and show well in the view, as does also a vertical set of northwest joints. So common are they that they soon came to be recognized as a matter of course, which it was superfluous to chronicle in the notebook. Hence the number of observations on joints striking n. 40° e.—n. 60° e. shown on the diagram [fig. 5] is misleading as to their abundance and importance. The com-

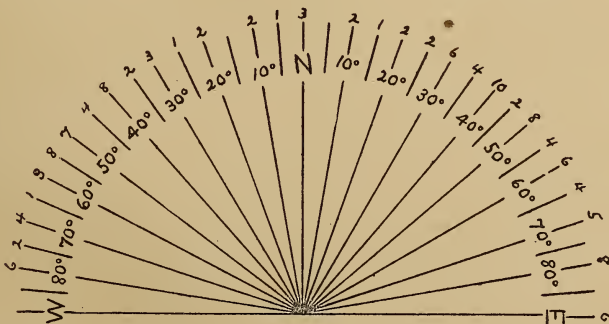


Fig. 5 Diagram to indicate the number of readings on joint directions in the Precambrian rocks of the district for each 5° point of the compass, the outer row of figures giving this number, and the inner row the compass degrees, corrected for variation

paratively slight variation in the number of readings for all points between n. 30° e. and east is however a result of, and indication of, the swerving of these joints with swerve in the rock strike.

The foliation of the Laurentian granite gneiss, and of the gneissoid portion of the Alexandria syenite is concordant with that of the Grenville rocks, and in them these same joint sets are developed, though in a much less prominent way. In the more massive igneous rocks they are replaced by a set of vertical, northeast joints.

At right angles to the set, or sets, of northeast joints is a set with northwest trend, with planes nearly or quite vertical, and ranging from n. 40° w. to n. 55° w. in direction, 27 of the readings falling within those limits. A less conspicuous east-west set is also indicated by the 12 readings between n. 70° w. and n. 80° w., together with the 14 between n. 80° e. and e. As seen in the field also this set is more variable and less prominent than the northwest set. The number of northerly readings is not great, and is spread rather uniformly over 50° of compass range, coinciding with the impression given in the field as to the comparative scarcity and great irregularity of that joint set.

Notwithstanding the rather small number of total readings the diagram shows that 30 out of the possible number of 36 different 5° directions are represented. Nowhere in the field were more than four sets of joints noted in a given rock exposure, and all the joints showed considerable tendency to curve and vary in direction, leading to the belief that this spreading of the readings is owing to this variability and in no wise indicative of a great number of joint sets.

Locally the more rigid of the Precambrian rocks, the quartzites and granites, are excessively jointed, the joints being very close spaced, chopping up the rock into small, angular blocks [see pl. 3]. In such places signs of slipping are usually to be made out. These so called "shear zones" result from readjustment under compression under conditions such that these rigid rocks fractured and slipped along the fractures, while those less rigid, the limestones for example, effected readjustment in other manner.

That the Precambrian rocks were jointed prior to the deposition of the Potsdam sandstone is conclusively shown, firstly by the absence in the Paleozoic rocks of compression joints and shear zones, and secondly by the occurrence of joint cracks in the Grenville limestones which became widened by solution and in that condition were filled with sand as the Potsdam sands commenced to be deposited. In the few cases in the district where contacts between Potsdam and Grenville limestone are exposed these features appear [see fig. 1, p. 58] and are apparently widespread.

In the Paleozoic rocks. In the Paleozoic Rocks of the district, Potsdam to Trenton, the joints are vertical, or nearly so, and show also considerable variability in direction, though this seems not quite so pronounced as is the case in the Precambric. Figure 6 gives a diagrammatic summary of 280 readings on these joints, and shows again a spreading to all points of the compass, 34 of the 36 possible

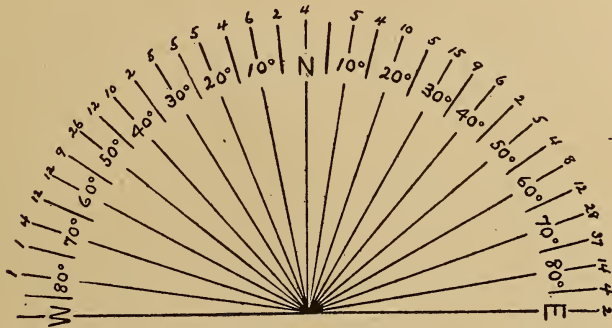


Fig. 6 Diagram, similar to that of the preceding figure, of the joints of the Paleozoic rocks

directions being represented. The great number of readings in the direction n. 70° e.-n. 80° e. constitutes the most prominent feature. The next point at which readings are concentrated is the n. 50° w. direction, but readings with this general trend are spread from n. 40° w. to n. 65° w., in other words these joints are somewhat less true in direction than those of the preceding set, which may however be regarded as extending from n. 60° e. to n. 80° e. A third direction of more abundant readings, from n. 20° e. to n. 40° e. is also shown, while the fourth direction, n. 10° w.-n. 30° w. is the least prominent of all. This last, however, is the one at right angles to the first, and most prominent, set. As thus outlined there are 99 readings for the first set, 81 for the second, 45 for the third and but 25 for the fourth. There remain 40 readings which lie wholly without these groups. It is to be noted that the mean directions of the four groups do not correspond with the cardinal points of the compass, but show a general deviation of 20° from them.

In the field the majority of the exposures exhibit but two good joint sets, though usually a third quite irregular set is present. With two good sets shown it is the exception that they are at right angles, and it is the east-west set and either the northeast or the northwest set with it, that usually appear. Often all three of these sets appear with lack of only the north-south set, and with the east-west set customarily the most prominent and regular. On bared rock sur-

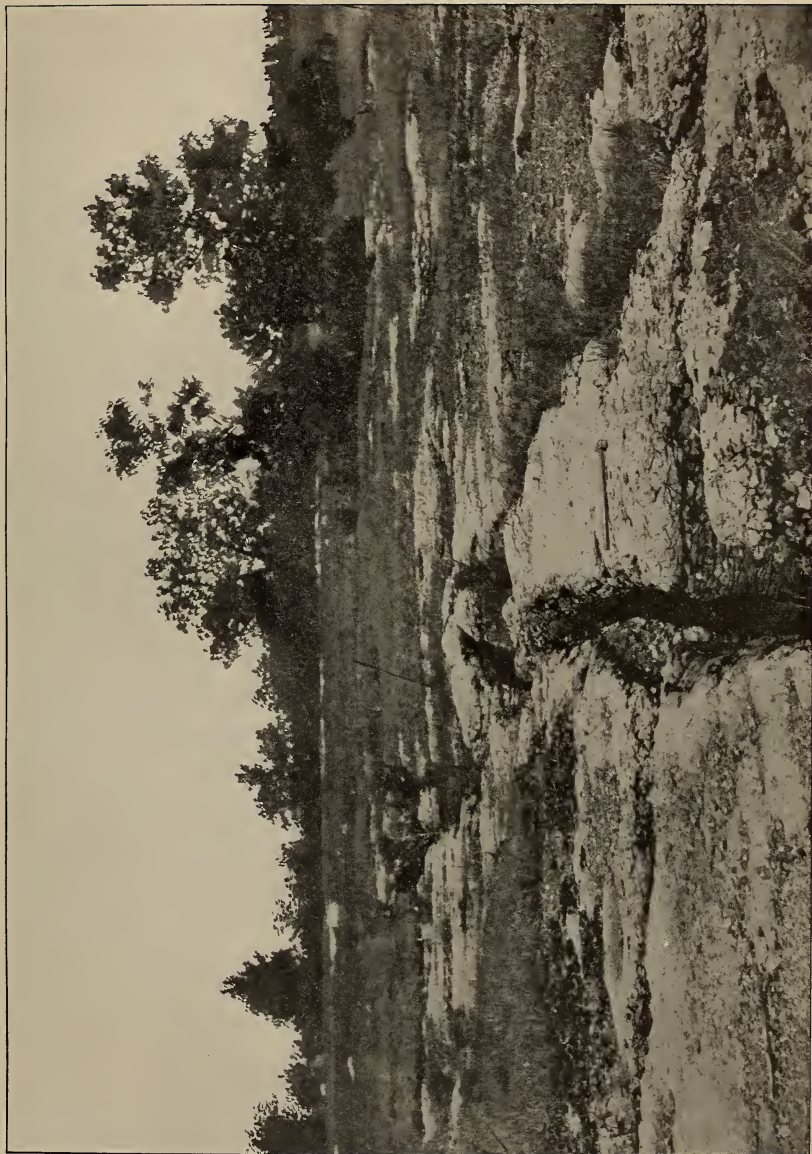
faces therefore the joints ordinarily divide the exposure into rhomboidal, rather than rectangular blocks. In plates 15, 20 and 23 joints are well shown.

The limestones of the district exhibit, in general, more abundant, more regular, and more clean cut joints than does the Potsdam sandstone. The limestones moreover are all somewhat soluble in rain water and underground water, the Black River and some of the Lowville beds being preeminent in this respect. The glacial deposits over the district are in rather scant amount, there being much bare rock exposed, and much more only thinly coated with soil. On the bared limestone surfaces the widening of the joint cracks produced by slow solvent action of rain water which passes underground along them, is magnificently shown [pl. 26, 27], most impressively perhaps in the Black River beds but almost equally well in the upper Lowville. In many fields which might otherwise be available for pasturage, the cattle must be carefully excluded, otherwise they fall into, and become tightly wedged in these gaping fissures. During our field work we came by chance upon a poor, stray cow in such plight in the vicinity of Limerick, tightly wedged in a fissure of sufficient size so that the animal's back was well below the ground surface.

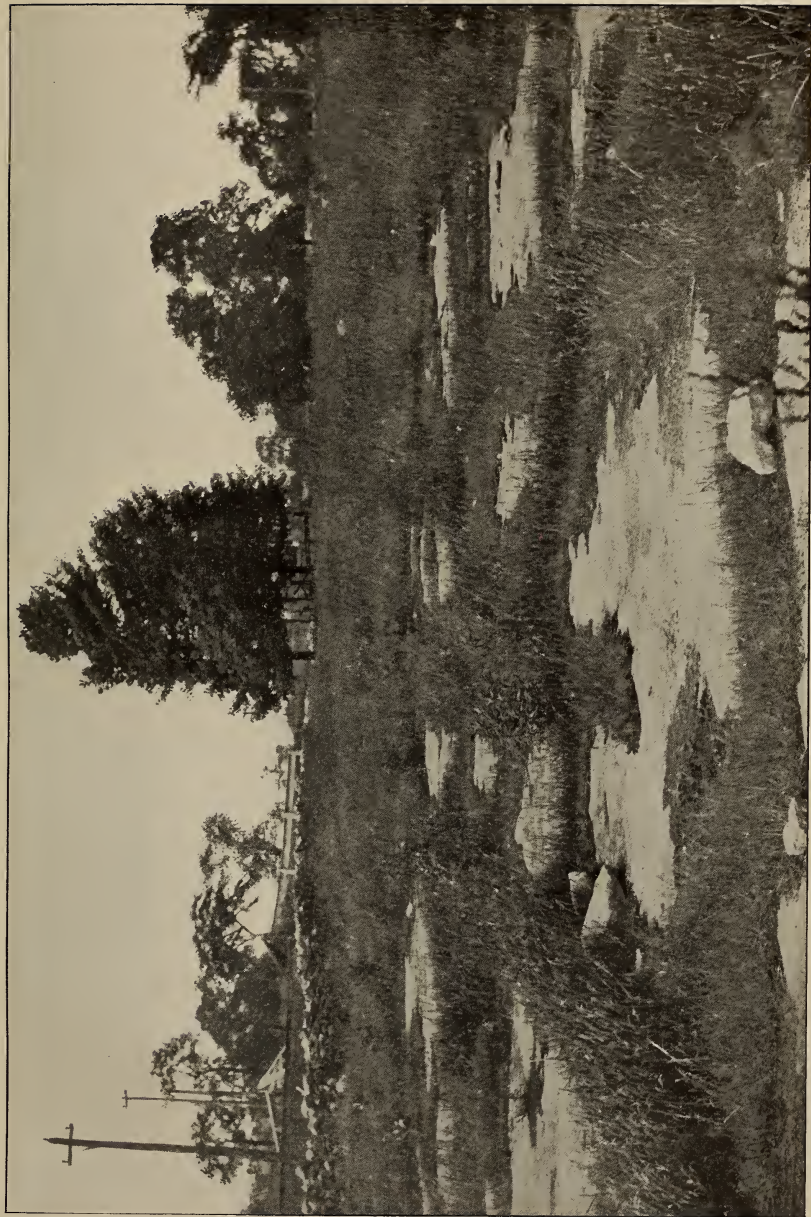
Down these widened joint cracks also the streams go underground, so that surface streams are infrequent in the Black River and upper Lowville districts. Beneath, this downward tendency is checked by the less soluble character of the remainder of the Lowville, on the upper surface of which these waters run along, eating away underground channels of considerable size in the soluble layers just above. In their early stages these channels are thoroughly roofed over, but as time goes on the roof tends to disappear, either by caving in because of lack of support by the widened channel underneath, or by slow dissolving away of the rocks above, thus bringing daylight down to the upper part of the tunnel. The matter will receive more detailed discussion when treating of the general drainage, but the details of the process and its varying stages are most excellently illustrated in the region [pl. 35-38]. While it is in many cases impossible to distinguish between preglacial and postglacial solution, it is nevertheless clear that much of this limestone removal is postglacial.

Folds

The rocks of the district exhibit various degrees of folding. The Grenville sediments are closely and intricately folded; the Paleozoic rocks show slight folding of Paleozoic date; and the same rocks



Bared surface of Leray limestone in field $1\frac{1}{2}$ miles west of Sanford Corners, Theresa quadrangle, showing solution along joints. H. P. Cushing, photo, 1907



Bared surface of upper Lowville limestone, $1\frac{1}{2}$ miles south of Sanford Corners, Theresa quadrangle, showing turf-filled joints. H. P. Cushing, photo, 1907



show occasional small surface folds, or buckles, produced since the ice sheet vanished from the region.

Precambrian folding. It has been shown that the Grenville beds are now found for the most part in highly inclined condition, dips of less than 45° being relatively rare, while those approaching verticality are common. Averaging the dips of the entire formation would give a result of at least a 55° to 60° dip. It has also been shown that the dip is not everywhere in the same direction but that, with the general direction of strike to the northeast-southwest, the dip, while prevalently to the northwest, becomes at times southeast. The southeast dips prevail over a belt of country some 4 miles in breadth in the Butterfield lake district of the Alexandria sheet. In the country lying south of this belt the dips are all to the northwest. In the other direction the Grenville is badly cut out by the syenite and granite of the Alexandria and Picton batholiths, but such as remains shows very steep to vertical dips, chiefly to the northwest. The highly tilted condition of the rock series, and these changing dips seem certainly indicative of folding. Moreover many exposures exhibit small folds of exceedingly compressed type, often accompanied by extreme plication. It is reasonable to suppose that these are merely secondary, or minor, folds superimposed upon folds of much larger scale.

In order to demonstrate the presence of these larger folds it is necessary that the order of superposition of the various Grenville beds should be worked out, and in the early stages of the field work it was hoped that this might be done. It is possible that it might have been successfully accomplished had large scale maps, say 4 inches to the mile, been available. But the structure is so complicated, the dips so steep, the folds so compressed, the series so greatly cut out by the igneous rocks, or so modified in character by them, and so much of the territory is yet covered by the Paleozoic rocks, that no certainty as to the Grenville succession could be arrived at with the maps in hand. Certain suggestions may however be made.

Inspection of the maps will show that the Indian river, from Theresa northward to the point where it passes off the Alexandria sheet, follows a broad belt of Grenville limestone, averaging somewhat more than a mile in breadth. Except for being much cut up by granite dikes and stocks, it is quite pure limestone. The dips are steadily to the northwest, and flatter than the usual Grenville dips, averaging about 45° , and hence indicating a thickness of about 4000 feet for the limestone. A few miles to the northward,

on the Alexandria sheet, what appears to be a quite similar broad belt of limestone borders the west side of Butterfield lake. It is however so much concealed by overlying Potsdam sandstone that some uncertainty attaches to its extent and purity. But it has a breadth of outcrop quite comparable to that of the Indian river belt, and *seems* to consist chiefly of pure limestone. Its dips are prevalently to the southeast, and somewhat steeper than in the previous case, averaging 60° . This means a thickness substantially the same as in the other case, and strongly suggests that the two are parallel outcrops of the same great limestone belt, and that, since they dip toward one another, the structure is synclinal. If this be the true interpretation then the schists, amphibolites and quartzites which lie between the two limestone belts, rest on the limestone and hence are younger, with the rather massive quartzites about Sixberry and Millsite lakes as the youngest of all; while the schists to the northwest on the Alexandria quadrangle, and to the southeast on the Theresa quadrangle, underlie the limestone and are older. Figure 7 will illustrate the suggested structure.

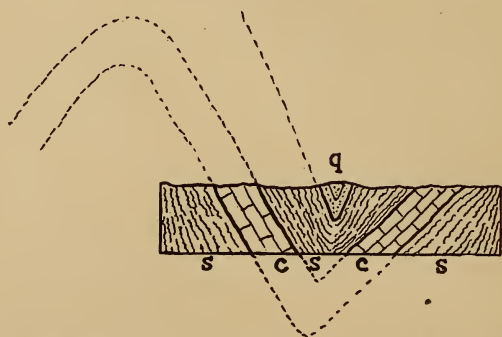


Fig. 7 Section to illustrate the structure suggested by the Grenville rocks, on a scale of 4 miles to the inch; s=schists, c=crystalline limestone, q=quartzite

There are, however, two alternative views in regard to this structure which may be held. It is possible that these two thick limestone masses may be separate beds, the one overlying the other and separated from it by the thickness of schist and quartzite which lies between. This involves the assumption that the series, though greatly tipped, is not folded and hence that no bed is cut by the present surface along more than one line. Since, however, small folds are certainly present in considerable number, the changing dips indicate the presence of greater ones, and as we have here two great lines of limestone outcrop, the rock showing much the same

thickness in each, and the two dipping toward one another, this supposition seems improbable in high degree. There seems no direct evidence for it and much against it.

The other alternative is that the structure here is anticlinal instead of synclinal. This is a possible interpretation of it in spite of the fact that the two limestones dip toward one another. Long continued and severe compression may so closely compress rock folds as to cause them to pass into the fan fold type as illustrated in figure 8. Such folds are so pinched that vertical dips prevail centrally, along the axes, and the dips farther away converge toward the axis in the anticlines, instead of in the synclines as in the previous case. In that also the dips flatten in the vicinity of the axis of the fold, and pass from one direction to the other through the horizontal, instead of through the vertical, as in the fan fold. In repeated instances, and in many localities, in the Grenville rocks of northern New York, the writer has observed that change in dip has taken place through the vertical instead of through the horizontal, and this seems to imply a condition of very close folding in the Grenville rocks at many and widely distributed points. In this especial case the dips change from the northwest to the southeast through the vertical in the schists northeast of Millsite lake, but with some comparatively flat dips in the interbanded quartzites north of the lake. At the same time the schists become greatly contorted and puckered. Millsite lake seems to lie closely along the axis of the fold. The section shown in figure 9 was sketched from an exposure $\frac{1}{2}$ mile northeast of Millsite lake.

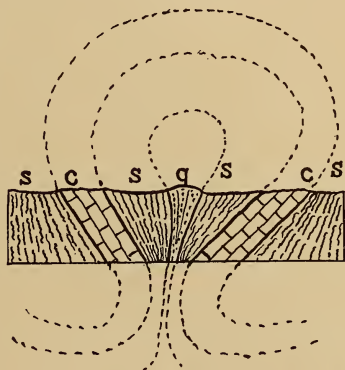


Fig. 8 Section similar to the previous, surface outcrops, dips and scale the same, on the assumption of fan fold structure



Fig. 9 Exposure of Grenville rocks $\frac{1}{2}$ mile northeast of Millsite lake, showing sharply folded quartzite q-q, with a pinched in thin limestone between the quartzite limbs, l, the quartzite succeeded on the left by hornblende schists, s, and very schistose mica schist, ms, the dip being vertical or nearly so throughout

The structure here is definitely anticlinal, though that is no indication of similar structure in the main fold, since minor folds on its flanks must consist of both anticlines and synclines. It will serve, however, as a sample of many similar exposures in the district which show clearly that the series is folded, and that it is closely folded. It also well illustrates the closely compressed conditions, steep dips, and minor folds which prevail in the vicinity of the axis of the supposed fold.

The writer's opinion is that the structure here presented is synclinal, similar to that depicted in figure 7. The discussion, however, serves to present the lack of certainty which prevails, and the possibility that the structure is of precisely opposite character. Either one indicates folding, but one precisely reverses the order of rock succession of the other.

It is also thought probable that the heavy quartzite along the axis of the supposed fold is the same stratum as the even more massive looking quartzite of Grindstone and Wellesley islands. If the structure be synclinal, as supposed, this quartzite is the youngest Grenville formation of the mapped district, but if anticlinal it is the oldest. If these two quartzite belts do represent lines of outcrop of the same quartzite formation, there should be an additional line of outcrop of the thick limestone somewhere between the two, in the near vicinity of the river. This does not appear but its absence is not a fatal objection to this interpretation of the structure, since the Grenville rocks there have been completely cut out by the granite of the Alexandria bathylith, and it is impossible to say what may have originally been there.

In summation it may be said that the Grenville rocks are greatly tilted, suggesting strongly compressive folding, and frequent small folds occur. Two belts of thick limestone and two of thick quartzite suggest a single formation of each in folded condition. Study of the dips suggests that this folding is of a certain type, but it is possible that, owing to very intense compression, the structure is just the reverse of that suggested. It has not proved possible to determine the order of succession of the various formations composing the Grenville, and to use that succession as the key for unraveling the structure, as is the usual method in folded rocks. Instead the attempt has been made to decipher the structure and from that to determine the order of succession, but with only indifferent success.

Paleozoic folding. While the Paleozoic rocks of the district show but a trifling amount of folding, it is of interesting nature

and to a certain extent at least is due to the pivotal situation of the region with respect to the early Paleozoic warpings, as has already been shown. In general the rocks lie, in nearly flat attitude, on the worn surface of the sharply folded Precambrian rocks. Over most of the district a low, southwesterly dip prevails; locally, however, the dip steepens to 5° or more, and dips occur in all compass directions. A strong westerly dip in the rocks along the Black river just above the bridge at Brownville is well shown in plate 28, and the dip is to the north, into the bank, as well, rock layers on the south side of the river lying some 10 feet higher than their equivalents on the north bank. In plate 24 a rather steep northerly dip in the Black River limestone at Watertown is shown, and in plate 21 a similar easterly dip in the same formation at another locality. These are samples of what is a matter of common occurrence all over the district. The areal mapping plainly brings out the presence of a series of folds which trend somewhat to the east of north. It also shows that the present stream valleys of the region in large part trend with these folds and chiefly follow the anticlines, while the synclines constitute the higher ground between.¹ Examples are the valleys running south from Theresa and from Evans Mills on the Theresa sheet; the French creek valley and the Chaumont valley on the Clayton sheet; and the Clear lake-Butterfield lake-Black creek valley on the Alexandria sheet; but there are many others of minor importance.

In addition to these nearly north-south folds there is a second set, about at right angles to the first, trending somewhat to the north of west, in parallelism with the Frontenac axis which is itself a fold of this group, the axial and most prominent one. Though mostly of minor importance, these folds are likely earlier than the others, and in part at least owe their existence to the warpings and tiltings of the region in early Paleozoic times, when it oscillated up and down, with tipping now to the east and now to the west. The Frontenac axis appears to be the major warp of this series, and the others are minor corrugations, grouped about it and diminishing in importance with recession from it.

¹ An anticline is the upward folding of rock layers into a long and relatively narrow arch; a syncline, the downfolding into a similar trough. Where erosion has removed the upper portion of such folds a worn off anticline is readily recognized on an areal map since it will show an older rock centrally, followed by successively younger rocks in the same order on each side; while an eroded syncline will show a younger rock in the center, followed by successively older rocks on each side. Thus the French creek valley, south of Clayton, shows Precambrian rocks centrally, adjoined by Potsdam on each side, Potsdam adjoined by Theresa and that by Pamela limestone, and the structure there is anticlinal.

In addition to the evidence which the general stratigraphy of the region furnishes as to the early date of some of this warping, evidence which has been already set forth, it also appears that the Potsdam and Theresa formations are somewhat more folded than are the overlying limestones, implying that they were somewhat folded prior to the deposition of the limestones. This is best shown in the district southwest from Clayton, along the valley of French creek, where the Potsdam is arched up into a prominent dome, even to the extent of bringing up the Precambric. The dome falls away to the south with rather steep dip, there is scant room for the Theresa formation between the south margin of Potsdam outcrop and the Pamela front just beyond, and this Pamela inface passes across the line of prolongation of this fold to the south yet shows no sign of being affected by it, being precisely the same cliff of horizontal limestone that it is to the east and west of this line. It is of course possible that a fault lies between, but the faults of the district are infrequent and insignificant, so far as known, so that the supposition seems unlikely, and the evidence seems to clearly point to folding and subsequent wear, during the long time interval between the close of Theresa and the beginning of Pamela deposition. Evidence of less distinctive character but of the same kind is also forthcoming elsewhere.

Two series of low folds intersecting at right angles result in producing maxima of elevation at the intersections of arches and of depression at trough intersections, with intermediate conditions where trough of one set meets arch of the other. In other words the axes of the north-south folds are themselves folded by the east-west folds, producing elevated domes along the arches, and depressed basins along the troughs. A prominent feature of the areal maps is the considerable number of outliers and inliers of the various formations there shown.¹ The abundant Potsdam outliers on the Precambric are more largely due to the irregularity of the floor on which the formation was laid down, than to the subsequent folding. But

¹ Along the southern margin of the Theresa sheet are shown a number of patches of Leray limestone, lying to the north of the main line of outcrop of the formation, and entirely surrounded by the older Lowville limestone. The Leray limestone formerly extended over the entire district, and has been worn away from much of it, these representing outlying patches or residuals left behind in this general process of removal, hence known as outliers. Inliers on the other hand are patches of an older rock entirely surrounded by a younger, such as the Precambric by French creek south of Clayton, or the Lowville near Threemile Bay and Threemile Bay creek, on the Clayton sheet. These are much less common than outliers and are strongly indicative of a warped upper surface of the formation constituting the inlier.



Lowville limestone, capped by Leray limestone, at Brownville, extreme southwest corner of Theresa quadrangle. View looking northeasterly, across the Black river and upstream, showing the westerly limb of one of the low folds which characterize the Paleozoic rocks. The water is slack water, back of a dam, hence the river surface is horizontal. H. P. Cushing, photo, 1908

in the case of the other formations the great majority of the outliers are owing to wear on rocks of this folded type. The numerous outliers of Leray limestone on the Theresa and Clayton sheets chiefly mark the positions of basins (points of intersection of synclines of both series of folds), the dips being everywhere in toward the center. Similarly the Lowville inliers which Ruedemann has mapped on the Clayton sheet, north of Threemile and Guffin bays, mark the summit of domes (intersections of anticlines) with dip outwardly from the center. In the case of some of the outliers however, those of the Theresa formation on the Potsdam west of Theresa for example, the dome structure instead of the basin structure is exhibited, the outlier showing no prominent inflexure, and with dip outward from the center. The domed structure often shows excellently elsewhere, as for example in the Theresa formation at Orleans Four Corners (Theresa sheet) where the upper surface of a single massive layer of the formation protrudes above the soil as a low, shallow dome, dipping outwardly in all directions. Many other examples might be cited and, owing to the abundance of rock exposures in the district the evidence of these structures is unusually clear, and it is quite certain that these two sets of low, cross folds occur.

Postglacial folds. There are in the district at least a half dozen examples of low folds, or buckles, of the surface rocks, which are of very recent origin. Though they form only a minor structural and topographic feature, they are rather unusual and the interest attaching to them is out of all proportion to their size and frequency. The writer has noted three of them in the limestones, Lowville and Pamela, and Professor Fairchild has called his attention to two others. In addition at least one occurs in the Potsdam sandstone. The limestone folds seem all to conform to a common type so that a description of one of them, and of the one in the Potsdam, will answer every purpose.

The Potsdam fold occurs 2 miles south of Chippewa Bay, in the northeastern portion of the Alexandria sheet, is near the roadside and easily visible from it. It is 40 yards long, trends $n. 28^{\circ} w.$, and a view of it, taken at the south end, appears in plate 29. It rises sharply from the surface of an extensive plain, underlaid by nearly horizontal sandstone, with but a scanty soil covering and much bare rock exposed. The fold is of bared rock with beautifully glaciated surface, whose striations demonstrate that the buckling has occurred since the glaciation. The central portion is buckled up about 12 feet. The photograph clearly shows that, owing to compression, the rocks

were bent upward until, the elastic limit being exceeded, the fold snapped along the crest, furnishing relief to the bent flanks and permitting them to straighten. In the rock here only a single set of good joints appears, and this runs at right angles to the axis of the fold separating it into a series of transverse blocks. On bending, these seem to have fractured individually instead of collectively, so that the axial fracture does not coincide in the different blocks, but departs from the median line, now on one side and again on the other, as illustrated in figure 10, giving rise to the dovetailing of slabs along the crest, so well shown in the photograph.

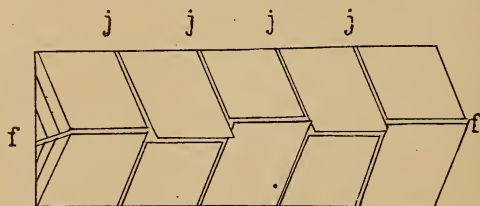


Fig. 10 Plan of fold in Potsdam sandstone, j-j=joints; f-f=fracture along crest, illustrating the manner in which the fracture shifts laterally in the different joint blocks, causing overlap of the rock edges along the crest.

One view of one of the folds in the Lowville limestone is shown in plate 30. The greater part of this fold is covered with soil, but centrally it has been stripped and a small amount of rock removed for local use. It seems to have about the same length as the previous one, and to be buckled up about the same amount. Its axis trends to the northwest. The rock is more closely jointed than in the Potsdam fold, and with two good sets present, one of which trends northwest with the fold, as the view clearly shows. Fracture then was unnecessary in this case and readjustment took place by utilization of these northwest joints, and instead of being actually folded, as might be judged from the photographs, the displacement really has the character shown in figure 11, as sketched on the spot.

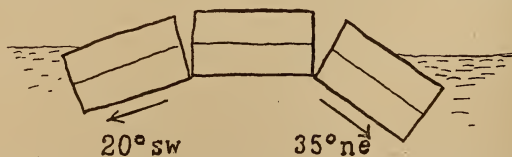
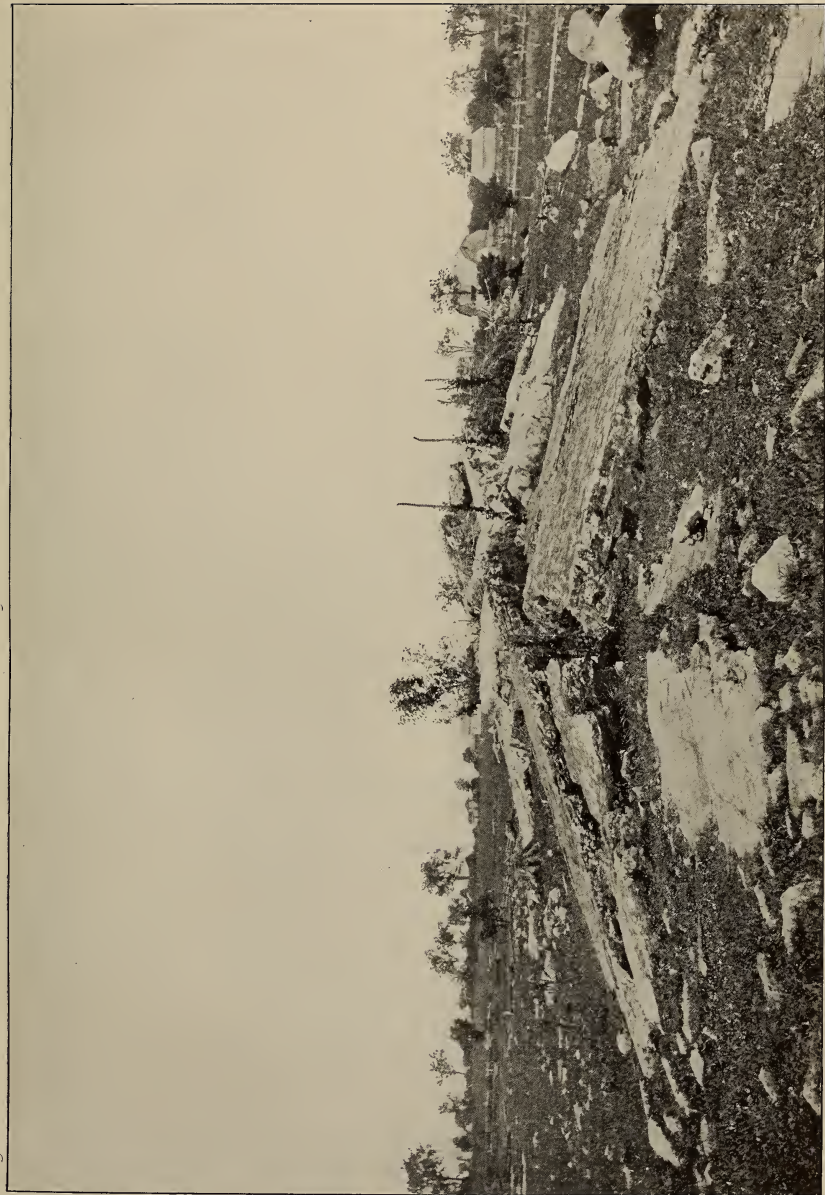


Fig. 11 Diagram to illustrate the arrangement of the joint blocks in the Lowville fold shown in plate 30. The central block lies nearly horizontally, the adjacent ones tipped in the directions and by the amounts indicated.

Small postglacial folds of similar type have been described by a number of authors and from various localities, and they have resulted from several different causes. Gilbert, after seeing some of



Postglacial arch in Potsdam sandstone, 2 miles south of Chippewa Bay, Alexandria quadrangle. The rock surface is glacially polished and shows the later date of the arching. The ruptured crest, and the dovetailing of slabs along the crest are also shown, and the set of cross joints. H. P. Cushing, photo, 1908



Postglacial fold in Lowville limestone, 1 mile west of Sanford Corners, Theresa quadrangle, looking northwest. The prolongation of the arch under cover as a topographic ridge is also shown. H. P. Cushing, photo, 1907

the limestone folds in this district, as well as others in shales in western New York and Ohio, demonstrated that they were superficial and postglacial, and attributed them to "horizontal expansion of superficial strata, consequent on postglacial amelioration of climate."¹ The writer does not question the correctness of this explanation as applied to the folds in shales and shaly rocks, which Gilbert describes, but is not so sure as to its adequacy in the case of quite massive, rigid limestones such as the Lowville, and is especially doubtful of it as applied to a well cemented, massive sandstone like the Potsdam, which is an exceedingly rigid and resistant rock. Postglacial climate is no warmer than was preglacial climate. Unless therefore the weight of the overlying ice was sufficient to cause some lateral spreading of the rocks, at the same time that it was producing contraction in them by lowering of their temperature, postglacial warming would merely reexpand them to their preglacial condition. There is no question as to the competency of the ice weight to produce lateral spread in shales and shaly rocks. Many shales are known to spread and to give rise to buckles under much smaller pressures, hence the cause suggested by Gilbert would seem ample to account for the results. But the pressure necessary to produce spread in a massive, rigid limestone is quite another matter, and that required in the case of such a rock as the Potsdam sandstone is of a still higher order. The weight of an ice sheet 1 mile thick would be equal to that of from 1700 to 1800 feet of average sedimentary rock. We do not know the thickness which the ice attained over this region but even the supposition that it was much more than a mile thick does not greatly enhance our figures of rock thickness. Are such pressures, even if applied continuously for a long time, sufficient to bring about lateral spreading in such a rock as the Potsdam? So far as known to the writer there are no direct, positive data which warrant a definite answer to this question. It is certain, however, that at such depths below the surface such rocks are abundantly fissured, are often porous, and permit free passage of fluids. This certainly suggests that they are not under sufficient weight to close up cracks.

If, however, this pressure due to the ice load could be reinforced by pressure from some other source in sufficient amount, the necessary lateral spreading could be brought about. A

¹ Gilbert, G. K. Am. Ass'n Adv. Sci. Proc. 35:227; 40:249.
Am. Jour. Sci. ser. 3, 32:324.

The writer is under great obligations to Dr G. K. Gilbert, J. C. Branner and H. F. Reid for references to the literature and for personal discussion of these folds.

very likely source of such additional pressure is to be found in the well known oscillations of level which the district has undergone preceding, during and since glaciation. The general district has increased its altitude by some 400 feet since the ice disappeared from the St Lawrence valley, and this change is simply the last of a series of oscillations. Furthermore these movements were of the nature of warps, the changes in level not being everywhere the same, but of varying amount. Such warping must bring about compression in some tracts and stretching in others. The contraction produced in the rocks by the cooling of the ice sheet would likely have manifested itself in mere slight widening along the joint cracks, and side compression brought about by warping may have sufficed locally to close up these widened joints. In such case postglacial increase of temperature might well tend to cause buckling of the rocks. The warping is of such nature that it would tend to produce thrust from the northeast, and it is to be noted that these folds trend northwest, as should be the case on this hypothesis.

There at once arises, however, the further question as to whether the compression consequent upon warping may not have been perfectly competent to cause the buckling, entirely independently of any effect which the ice may have had, and this seems to the writer very probable. Dr Reid, in correspondence, states his belief that "we must fall back on the general explanation that movements of the crust are in progress which have produced these bucklings." Dr Branner expresses similar views. In any case, until it has been shown that lateral spreading may be produced in rocks of this resistant type by load no greater than that of the ice sheet, some doubt must attach to the competency of Gilbert's hypothesis as applied to these special cases.

Faults

Faults of considerable magnitude and importance have not been noted in the district, and the fairly accurate areal mapping which the abundant rock exposures render possible, indicates that no such are present, at least in the Paleozoic rocks. Small faults appear, however, in considerable number in all the rocks and are apparently of different age.

In the Precambrian rocks. Small faults, with dislocations of from a fraction of an inch to a few feet occur in a great number of localities in the Precambrian rocks, as already pointed out by

Smyth.¹ The numerous dikes, chiefly of granite, which everywhere cut the Grenville give every facility for determining their presence. They are in great number but for the most part of very trifling displacement. Similar faulting locally in the Paleozoic rocks suggests that this faulting is of Paleozoic date, but the much greater number of faults noted in the older rocks indicates some Precambrian faulting at least, and of this there is direct evidence in some instances. The hand specimen shown in plate 5, lower figure, presents an adequate illustration. The rock is a well banded, acid Grenville gneiss, consisting chiefly of feldspar and quartz and seems certainly a sediment, a metamorphosed shaly sandstone. The bands vary in color from a light reddish to a blackish red, and are very plain, though without sufficient contrast to photograph clearly. They are parallel to the bedding and seem certainly to represent original lamination in the rock. Shearing has occurred, with development of fracture cleavage, principally at a high angle with the bedding, but with secondary fractures which rudely follow it, and along many of the former minute slips of the rock have taken place. These old cracks are now solidly welded up with secondary minerals, black in color, except for an occasional, shining pyrite crystal, and it is this secondary filling which furnishes the evidence for the date of the deformation and gives the chief interest to the rock. Pyroxene, hornblende and black mica (biotite), stated in order of abundance, are the minerals composing the filling, their grain somewhat coarser than that of the rock. They are of the same types as the minerals of the Grenville green schists. They argue for fairly deep seated conditions at the time of the deformation. The fractures show that the rock was above the zone of flow, but the minerals, the pyroxene especially, indicate anamorphic conditions and point to deformation in the lower part of the zone of fracture. Such faulting seems not only of Precambrian date, but to have preceded the greater part of the long, Precambrian erosion interval. Its date is made quite certain by the numerous dikes of Picton granite which cut the schists, the granite being younger than the filling of the shear zones.

There are also frequent shear zones in the Precambrian rocks, zones of no great breadth but of considerable linear extent, along which the rock is shattered into quite small blocks by a multitude of close spaced joints, and along which some faulting has certainly taken place, small slips along many planes. No such shear

¹ N. Y. State Geol. 19th An. Rep't, pl. 15.

zones have been noted in the Paleozoic rocks, and the deformation which gave rise to them seems certainly of Precambrian date, though later than that previously described since the rocks were under less load, hence nearer the surface.

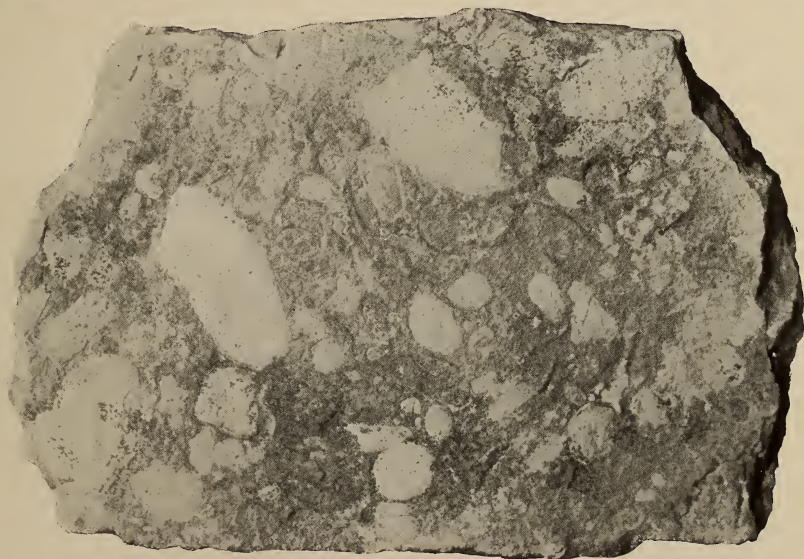
In the Paleozoic rocks. Frequent faults of small throw may be made out in the Potsdam sandstone. The red and white banded stone which constitutes the lower part of the formation on the Alexandria quadrangle is excellently adapted to display them, and a magnificent exhibit of them is given on the bare rock surface of the large Potsdam outlier which lies between the railroad and the north end of Butterfield lake. Here over a considerable area the faults are spaced but a few feet apart, and though the throw seldom amounts to as much as a foot, and is frequently only a fraction of an inch, the combined displacement of the whole must be quite considerable, as there are hundreds of them. For a hand specimen from this locality, showing one of these faults see plate 31, upper figure. All noted are normal faults of slight hade. The fault planes are filled with sand grains in all respects like those of the rock itself and as thoroughly cemented, which would seem to indicate that the faulting occurred before rock cementation was far advanced, so that the grains gave way individually instead of as sandstone fragments, whereas the latter would certainly be the method were faulting to take place in the rock now. Cementation subsequent to the faulting has thoroughly indurated the whole.

The bulk of the formation is rather uniformly colored and hence not so well adapted to display faulting of this type, and it is not certain whether it occurs in it or not.

There are also occasional small faults of a later type in the Potsdam, the fault planes remaining as open cracks, with sandstone fragments in the fault breccias. A small fault of this type appears in plate 12.

In the limestones a few faults have been noted whose throw amounts to several feet. The best example seen by the writer is in the lower Pamela limestones of the Pamela inface, 2 miles east of Perch lake. The section here shows the basal, black, fossiliferous limestones, overlaid by a thickness of some 15 feet of thin bedded, earthy limestone, followed in its turn by massive blue limestone with interbedded gray magnesian layers. These upper massive limestones are faulted down against the earthy limestone, the fault bearing $n. 30^{\circ} e.$, downthrowing to the east and with a throw of some 20 feet.

Plate 31



Upper figure. Hand specimen of faulted Potsdam sandstone, nearly natural size. The rock is red, with white streaks, and the fault plane is filled with white, thoroughly cemented sand.

Lower figure. Hand specimen of basal, Lowville conglomerate from near Depauville (Clayton quadrangle). The pebbles of fine limestone mud, of dove color, weather prominently white, as compared with the remainder of the rock surface. H. P. Cushing, photo

Ruedemann has mapped two small faults on the Clayton and Cape Vincent sheets and furnishes the following description:

In Chaumont village (Clayton sheet) is a small outlier of Trenton limestone, immediately to the west of which, and at the same level, is Watertown limestone. The relations are best seen about the viaduct on the Depauville road and along the railway immediately to the east. Under the viaduct is Watertown limestone. Along the railroad is Trenton at the same level, with a cut which shows steeply dipping Trenton, the dip being away from the Watertown and apparently due to drag on the downthrow side of a fault. The fault downthrows to the east, with a throw just sufficient to preserve the small patch of Trenton on the downthrow side. Its trend is substantially parallel to the road, or about northeast.

On Carleton island (Cape Vincent sheet) the presence of a fault cutting off the small western promontory, which consists of Watertown limestone, is suggested by the depression which separates the promontory from the mainland, within which no rock shows, and which is faced by a rock cliff on each side, a high Trenton cliff on the main island side and a lower cliff of Watertown on the other. A small fault along the depression, with downthrow to the east, is thus indicated.

TOPOGRAPHY ¹

The present day topography is the result of erosional forces acting for long ages upon a land surface, which from time to time varied in altitude and which underwent climatic changes. The character of the erosion, and of the resultant topography are also conditioned upon the character, attitude and structure of the rocks comprising the region. We have some slight knowledge of the changes in altitude of the region. The climate has certainly varied much, both in respect to temperature and to humidity, with, in quite recent times, the climatic rigor of the glacial period. The erosional forces, as always, have been in part atmospheric, but chiefly those of moving water and ice.

During paleozoic times the region was, when not submerged, one of low altitude. It was uplifted somewhat at the close of the Paleozoic, and during Mesozoic time seems to have been worn down to a comparatively even surface of low altitude, in common with much of the eastern portion of the continent. During the succeeding Tertiary it participated in the general uplift of the same region, and its present relief is chiefly a product of Tertiary wear.

¹ By H. P. Cushing.

Paleozoic altitude and climate

During the Lower Siluric the immediate region was from time to time submerged, at other times was above sea level. During submergence there were neighboring lands. It is apparent that all were of low altitude. During emergence there was but trifling wear on the exposed land surface. During submergence the adjacent lands furnished but little land wash, though the Precambrian rocks of which they were formed were capable of supplying great quantities of sand and mud under conditions of any freedom of drainage; and they were near at hand and of much extent. A small thickness of sand marks the horizon of the Pamela-Lowville break, otherwise the formations are unbroken limestone, until the shales of the upper division come in; and these are more indicative of stronger currents in the marine waters, than of especially increased altitudes of the neighboring lands. The succeeding Oswego sandstone seems a continental, rather than a marine deposit and indicates freer drainage and somewhat greater altitude.

But little has been gleaned from the region itself as to climatic oscillations in these early times. The upper Pamela was marked by a somewhat arid, and perhaps warm climate, as has been seen. Probably the same was true of the Oswego-Medina, though that lies outside our district. The Potsdam climate is a puzzle. Farther east, where the basal Potsdam consists largely of arkose, and where the Precambrian underneath shows the same freshness and the same irregularity of surface under the Potsdam that it does here, we have expressed the opinion that the sandstone was a continental deposit, so far as the basal portion is concerned, and that the climate was arid. Here however, with the same character of floor, we have a pure sand deposit, instead of arkose. The unweathered character of the Precambrian rocks, the absence of residual weathered material, except in very scanty amount in the most sheltered situations, and the general base-leveled character of the surface, seem to point to long continued wear under conditions of aridity and removal of disintegrated material by the wind. Under those circumstances however the residual products should be arkose, instead of pure quartz sand such as constitutes the Potsdam here. There is much more feldspar in the basal Pamela sand than in the Potsdam, and even in that it is not in great quantity. We are unable to correlate this quartz sand with conditions of climatic aridity, and equally unable to explain the character of the Precambrian surface, and the unweathered condition of the rocks, satisfactorily to ourselves, on any other basis.

During the remainder of the Paleozoic we know but little concerning the region here, except by comparison with other regions more or less remote from it. It may have been somewhat submerged during the Siluric, but certainly, for most of the time, it was a land area, and the small amount of wear which it experienced indicates that, for most of the time, its altitude was low.

Amount of erosion

The total amount of rock thickness which has been worn away since the region became a land area, can not of course be exactly determined, though it is thought that it can be approximated. To the south the Trenton limestone is overlaid by the Utica and Lorraine shales, and these by the Oswego sandstone and Medina shale and sandstone. These are all sufficiently near to make it in high degree probable that they were laid down over our district, especially since the source of their sediment must have been to the north and east. It is regarded as unlikely that they had any greater thickness here than they now show toward the south, but they may have been as thick. We have no evidence that any formations later than the Medina were ever deposited here, and even if so, the thickness would seem to have been small and the submergence brief. If therefore we allow to these formations the full thickness which they show to the south, we are likely exaggerating their thickness here and allowing a margin to account for any possible later formations which may have existed.

The deep wells which have been drilled at various points between this district and the Syracuse region, give the data desired. In the Monroe well at Baldwinsville the drill went through 1740 feet of sandstone (Medina-Oswego) and shale (Lorraine-Utica), reaching the top of the Trenton at 2240 feet. If we assume them to have been deposited over our district in the same thickness, and add the thickness of underlying rock (Potsdam-Trenton) we get 2600 feet as an outside measurement of the Paleozoic thickness here originally. In all probability this is considerably too high. There were 1200 feet of sandstone and 500 feet of shale above the Trenton in this well, and the full thickness of both was passed through by the drill. In the wells further north, as in Orwell and Central Square, less sandstone appears but the shales thicken to 700 feet. Since no certainty is possible our purpose is best subserved by a generous estimate, and an original thickness of 3000 feet of Paleozoic rocks here will be assumed. Where Precambrian rocks are now at the surface, 3000 feet is regarded as the outside limit of the thickness

of overlying rock which has been worn away, from the close of the Siluric to the present. Where the various members of the Paleozoic form the surface rocks, erosion is correspondingly less, and since the Precambric is at the surface over but a small fraction of the region, the general erosion has been less than that figure. Considering the great length of time involved, this represents no great erosion, and seems to point to land of no great altitude for much of the time. It seems to be further demonstrable that at least one half of this erosion took place in Tertiary time, which argues all the more strongly for general low altitude during the preceding ages of the Mesozoic and later Paleozoic.

Original drainage

As uplifted at the close of the Siluric, and following the deposition of the Oswego sandstone, our area became the marginal portion of land masses to the north and the east, and in all probability possessed a gentle slope to the southwest. The original streams must have followed down this slope to the margins of the later Paleozoic water bodies of central New York, thus flowing in the direction of the rock dip, and at right angles to the strike. Having taken position they would commence to carve valleys, whose possible depth would depend upon the altitude of the land. Streams of this type are called consequent streams. With valley cutting in progress, tributaries to these original streams commence to develop, beginning as gullies in the valley sides, and steadily cutting headwards. Obviously they form most readily where the valley walls are weakest, and tend to remain in the weak rock belts, following their strike, hence with courses which make substantially a right angle with those of the original streams. Such streams are called subsequent, since their development must wait on that of the consequent streams. With a belt of weak rocks to follow, these subsequent streams may eventually become the chief streams of a region, diverting or "capturing" the headwaters of the old consequent streams. The Utica and Lorraine shales constitute such a weak rock belt in this region, with the great Ontario valley eaten out along it, the Adirondack highland blocking its extension further east.

With chiefly low lands, drainage adjustments would go on but slowly, and the drainage may have been considerably modified from time to time by tilting of the land, under these low altitude conditions. With the passage of time, however, it has come about that the chief streams of the region are now in subsequent position,

and there is little trace of the old consequent streams, though the streams running westerly, out of the Adirondacks, seem to represent the old heads of such streams.

Tertiary uplift

Evidence derived chiefly from without the district indicates that our region, in common with much of eastern North America, was worn down to a comparatively smooth surface (peneplain) of low altitude by the close of Mesozoic time. It then experienced considerable uplift, erosion was renewed and streams cut and widened considerable valleys in the weaker rock belts, while the more resistant rocks retained in considerable measure their original altitude, and give us the remnants of the old plain. Elevations of over 1500 feet are found on the Watertown sheet, immediately south of our map. On the Port Leyden sheet, next south, the altitudes reach almost 2000 feet, the district there forming a low plateau, capped by the resistant Oswego sandstone, between the Ontario lowland to the west and the broad valley of the Black river to the east. East of the valley the levels rise within a few miles to 2000 feet, in the westerly edge of the Adirondack platform, and from there continue to slowly rise eastward. The Adirondack highland, and the Oswego sandstone plateau, are regarded as remnants of the old peneplain surface, which as uplifted, was given a slight tilt toward the west, while the deep valleys of the region have been cut since the uplift and give some measure of its amount. Unless later rocks in considerable thickness have been worn away from the surface of the Oswego sandstone plateau, the amount of wear there has been very slight; yet this small thickness of removed rock represents the general erosion over the entire region from the close of the Ordovician to the close of the Cretaceous, a wear so slight as to be only compatible with low altitude of land when the length of the time interval is considered.

Tertiary drainage

The Tertiary uplift of the region gave to the land an altitude in excess of that of the present. A partial measure of this excess is the difference in level between the Tertiary valley bottoms and those of today; but we do not know the depth of valley filling in this district and hence can not state the excess. Even before the uplift the streams had likely become adjusted to much their present relation, namely consequent streams flowing westerly

and northwesterly out of the Adirondack region, and southerly and southwesterly out of the Canadian Precambrian region, and these streams diverted by the large subsequent streams in the Black river, St Lawrence and Ontario valleys; the Black along the overlap of the sedimentaries on the crystallines, the Ontario valley on the thick shales, and the St Lawrence on the limestones of the depressed trough, with bordering Potsdam and Precambrian on both sides; hence each on a relatively weak rock belt. In these positions the Tertiary successors dug out their valleys. They mostly flowed as they do now, the important exception being in the case of the Ontario-St Lawrence drainage. The fold, or warp, of the Frontenac axis crosses this drainage line in our district. Even before being worn down to the Precambrian this would make a natural rock barrier to the drainage, since the lower Ordovician rocks are more resistant than the upper, and hence form a divide or col between waters flowing northeast, down the present St Lawrence valley, and waters passing west through the Ontario valley, the Black river forming the chief stream of the immediate region, as it now does. All writers on the district have considered that, in Tertiary times, the Black river turned westward into the Ontario valley. Wilson especially has considered the drainage of the immediate region in some detail in a most excellent paper, with much of which we are in entire agreement.¹ He points out that the St Lawrence lacks a definite channel in the Thousand Island region, going over the Frontenac axis at its most depressed point. With this we agree, but we do not coincide with his view that the Black river, in its course across the mapped area, is closely in its preglacial channel (the river below Carthage is here referred to). We are however in doubt as to where this preglacial channel was. Fairchild disagrees entirely with the view that the preglacial waters of the Black river went westward, and turns them into the St Lawrence valley below the col. His views are presented on pages 141-145. I dissent somewhat, preferring the view that the drainage went into the Ontario basin, but must frankly admit that I have not discovered the precise route followed, so that it seems to me that opinion in the matter must be held in abeyance, pending discovery of the actual old channel.

If the Frontenac axis formed a divide here in Tertiary times such divide should run across our district toward the Adirondacks, as a divide between streams going north and those moving

¹ Geol. Soc. Am. Bul. 15:236-42.

west. The presence of this divide, with its sharply cut ravines heading against it on both sides is to us one of the most interesting features of our district. It is most unfortunate that the maps of the quadrangles next east are not available so that it could be further traced in that direction. Inspection of the Alexandria and Theresa maps will show plainly its course across them. In the low grounds near the St Lawrence the ravine heads are not prominent, though the two lateral ravines into Cranberry creek valley from the east are good examples. But at Browns Corners, 4 miles southeast of Alexandria Bay, is seen the head of the first of a series of sharply cut valley heads with northeast trend. The next is at Plessis, dropping down sharply into the Clear lake-Mud lake-Butterfield lake valley, with a secondary sharp drop at the head of Butterfield lake. One and one half miles southeast of Plessis, on the extreme south margin of the Alexandria sheet, is the head of the Hyde lake-Hyde creek-Perch river valley, on the other side of the divide, belonging to the southwest drainage. Just east are two sharply cut ravines heading on opposite sides of a low pass across the divide, the valley of Crystal lake, which is tributary to the Mud lake valley, and the valley without present drainage, followed by the railroad and leading south into the Indian river valley on the Theresa sheet. This valley is somewhat more blocked by drift than the others and seems to have held a shallow lake. The Millsite lake and Sixberry lake valleys also head sharply against the divide on the north. They are however of somewhat abnormal type. Most of the other valleys mentioned commence as distinct but shallow, rock-cut trenches, which, after a short course, suddenly deepen to gorges with walls from 40 to 100 feet high. The Clear lake and Hyde lake valleys nicely illustrate this type. The lakes are at the heads of long valleys leading away from the divide. The Crystal lake, Sixberry lake and Millsite lake valleys, on the other hand are short valleys, tributary to others at the side, and they deepen almost at once, instead of having the preliminary shallow course. The view of the head of Crystal lake valley [pl. 34] gives an excellent idea of the general character.

Passing to the Theresa sheet, attention is at once directed to the considerable and deep valley, leading north past Theresa, the valley into which the modern Indian river breaks at that point, with production of falls and short gorge [pl. 32]. The valley itself heads 3 miles further south. Two miles to the west is the Hyde creek-Perch river valley, running southwest and heading

on the Alexandria sheet, as we have just seen. This parallel, but northerly-flowing Theresa valley plainly heads several miles south of the original line of the divide, in other words has pushed it south out of line by headward cutting of its valley. Its ability to do this was no doubt conditioned upon the weak resistance of the Grenville limestone belt there. Once the Potsdam was cut through, rapid headward cutting of the stream would be possible. From the present valley head a shallow valley runs southwest to Perch lake, and it seems clear that formerly this valley headed along the old divide, and was diverted, bit by bit, by the more advantageously situated stream flowing the other way. The minor tributary valleys from the east and west, between Theresa and the north margin of the sheet, are southerly trending valleys, southeast or southwest, and hence adjusted to a southerly, rather than a northerly flowing stream. The northerly flowing stream slowly captured and reversed the headwaters of the south stream, extending its capture through a distance of from 4 to 5 miles.

Northeastward from Theresa are a number of valleys heading sharply against the Potsdam mass which there forms the divide, and leading away from it to the southwest. These are located on belts of Grenville limestone, or of weak schist, and therefore are broader and less ravinelike than most of such valleys in the district. They are, however, comparatively narrow, distinctly rock walled, and with present flat-bottomed floors owing to drift deposits.

Here, in the northeast corner of the Theresa sheet, the divide runs off our maps to the east, and with maps of that district not yet available, its further course can not be traced. It, today, rises steadily in altitude in that direction, and is, as in Tertiary times, the divide between waters flowing north to the St Lawrence and west to the Ontario valley.

The Indian river of today, from Theresa south to the great bend north of Evans Mills, is flowing in reversed direction through what was then the valley of a small stream heading near Theresa and flowing south. Wilson's view is that at the bend it was tributary to a southwest stream, occupying the valley now followed by Indian river above the bend; and that their combined waters flowed south through the present West creek valley to the Black river. With our disbelief in the presence of the Black river there at that time, coupled with the fact that the West creek valley seems both to widen, and to deepen,



The smaller of the two gateways at Theresa through which the Indian river passes into the preglacial valley. The rocks are steeply dipping Grenville schists. H. P. Cushing, photo, 1907

northward, we are in doubt as to the correctness of this view. Certain it is, however, that the present course of Indian river is a patchwork of various preglacial valleys, the modern character of the course being most excellently shown at Theresa where the river drops 80 feet, from a shallow valley into a much deeper one, entering this on its east side 3 miles below its valley head, with cutting of a short, postglacial gorge in the old valley side.

Plateaus, terraces, scarps

With the streams cutting down valleys and exposing rock formations of varying age and resistance in their valley walls, and with the slow widening of the valleys, the stronger rock beds of the region tend to outcrop in cliff form, the scarps running across country in the direction of strike, and curving up the consequent valleys in the direction of dip. The stronger cliffs result where a more resistant rock overlies a considerably less resistant one, the more rapid wear of the underlying rock tending to keep a tolerably steep and precipitous cliff front. Where the differences in resistance are less, or where rapid changes in resistance occur, involving no great thickness of rock, low, subdued scarps are produced.

Furthermore, where an overlying formation is weaker than that beneath, rapid wear is checked at the upper surface of the lower rock, the upper rock is stripped away from it and a flat bench of varying breadth is produced, separating the cliff fronts of the upper and lower formations. In the large way, ignoring minor complicating factors, the general topography of our district is of this type: flat platforms developed on the surfaces of the hard layers, and cliff fronts which mark the descent from one rock platform to the next, the cliff fronts facing toward the old land area, in this case to the north, hence often called infaces.

The most prominent cliffs, and the broadest platforms of the district are those of the Potsdam sandstone, as it usually has considerable thickness, is the strongest or most resistant of the Paleozoic rocks, and more enduring than much of the Precambric, on which it rests. The Precambric topography has already been described, and this does not need repetition. The Potsdam is thickest where the underlying Precambric is weakest, the bulk of the remaining Potsdam rests on these weaker rocks, this being notably true in the case of the outliers. Potsdam cliffs from 20 to 60 feet high are abundant throughout the district, and are absent only where the underlying rock is granite and the Potsdam very thin. Broad Potsdam

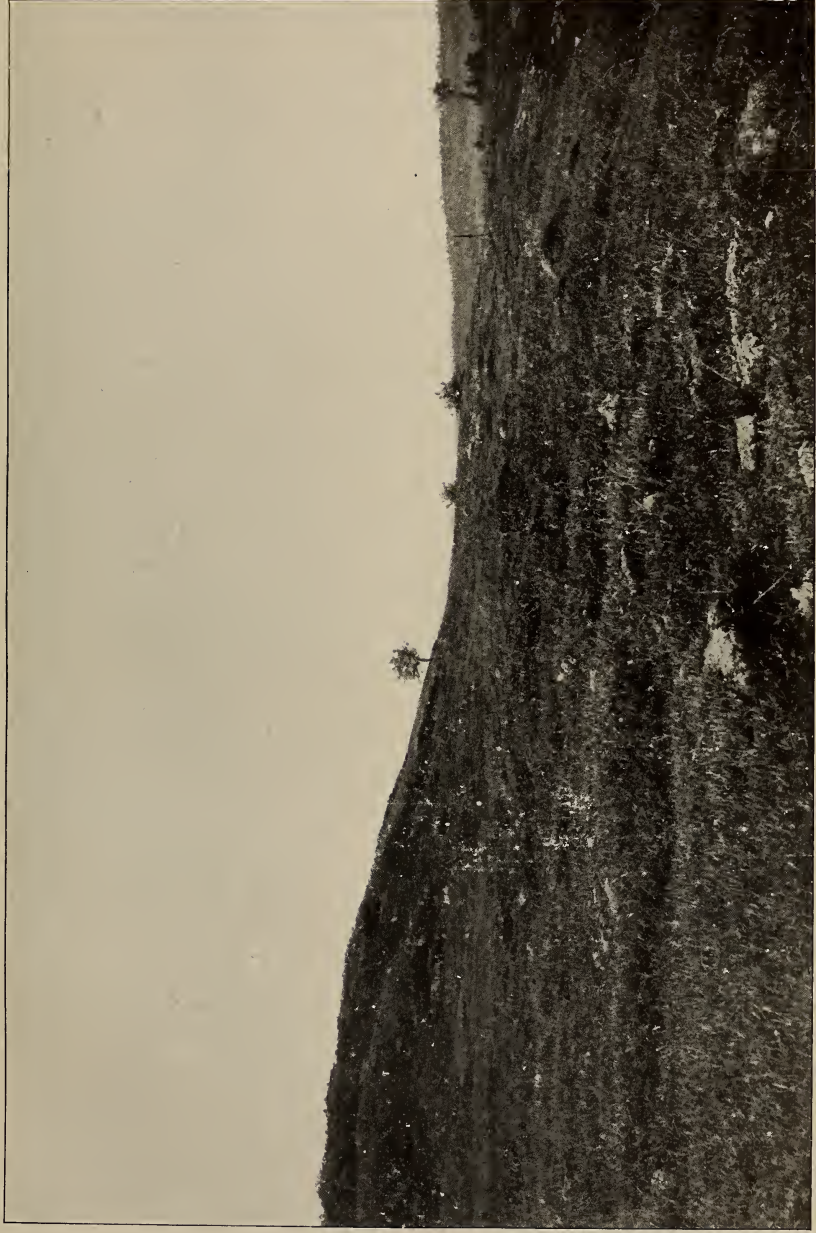
platforms are well shown on both the Theresa and Alexandria sheets.

Though the Potsdam as a whole is strong, the uppermost beds, together with the sand beds in the basal Theresa, form a weak combination, in which the massive bed of the Potsdam summit is relatively strong. The overlying Theresa is also stronger than this weak zone, and hence the Theresa edges form rather prominent infaces, with these weak beds at their base; not infrequently also the strong summit bed of the Potsdam forms a narrow platform of its own, part way up the inface [pl. 33]. The Theresa rocks weather to iron stained crusts and their exposed edges have a thin bedded look, giving these infaces a peculiar and unmistakable look of their own. Above the base the Theresa shows rather rapid alternations of thicker and thinner bedded layers, the former somewhat more resistant, so that low infaces of these various layers are frequent throughout the Theresa country.

The sandy basal layers of the Pamelia formation, some 25-30 feet thick, constitute the weakest zone within our map limits, and are readily stripped away from the Tribes Hill underneath, while the overlying limestone is more resistant, so it is not surprising that the Pamelia cliff front is one of the most conspicuous topographic features of the district, a feature which the contour maps clearly bring out. In front lies a flat Tribes Hill platform. The cliff ranges from 20 feet to more than 100 feet in height, but is usually from 50 to 60. Higher up in the formation the occasional very massive limestone beds form frequent low infaces of their own, as in the case of the Theresa formation. The Lowville differs but little from the Pamelia in resistance, and has no zone of weakness at its base, hence is not fronted by a prominent inface of its own, and is the only formation which lacks one. It has its own minor fronts, but these are of the same order of magnitude as those of the upper Pamelia beneath.

The Leray is a thin formation, but because of the massiveness of its beds, and the abundance of chert in its lower portion, it everywhere forms infaces with distinct characters of their own, of which the curious blocky type of weathering is the most conspicuous [pl. 20]. The 7 foot tier above also has a front of its own.

The thin bedded Trenton limestone is considerably less resistant than the Watertown, hence the Watertown platform in front of the Trenton inface is comparatively broad, especially when the small thickness of the formation is taken into consideration. Notwithstanding the weakness of the Trenton, its inface to the south of the Black river is far the highest and most commanding of the



North face of Theresa escarpment, $\frac{1}{4}$ mile southeast of Clayton, looking west. Theresa dolomite on left, upper surface of Potsdam sandstone on right and in foreground. H. P. Cushing, photo, 1908

region. Only a little of this is within the map limits, in the extreme southeast portion of the Theresa quadrangle. Such Trenton as there is north of the river shows itself in rounded hills without prominent inface and this is its normal and usual character. The high cliff referred to is unusual and due to proximity to the Black river.

Minor modifications of these general features are produced because of the low folds of the Paleozoic rocks. The discussion of these has shown how low domes and shallow basins are thus produced in the rocks, resulting in the formation of outliers and inliers of the various formations, with their local infacing or outfacing cliffs; resulting also in a lobation of the general formational infacing fronts. As Ruedemann has stated these lobes are most conspicuous in the Leray fronts, an additional cause being there at work to accentuate them. Nevertheless they are primarily due to the folding, the other infaces showing similar, even though less conspicuous lobes. The topographic maps show these general features excellently.

The lowlands of our region today are chiefly the result of the stream wear during the Tertiary. The prominent rock infaces and platforms of the various formations are owing to the considerable differences in level between the low grounds and the adjacent uplands, and terrace broadly the ascents from the one to the other. These features, together with those of the drainage outlined above, were substantially what they are now at the end of Tertiary time. There are few northern regions in which the general topography is so little changed, and has its Tertiary features so little masked by subsequent Pleistocene changes as is the case here.

Lakes

The group of lakes in the southeastern portion of the Alexandria quadrangle, together with a few more of the same type in the district to the eastward, constitute one of the very interesting features of the district. Their interest arises in part from their localization; they are abundant in this restricted area and are scarce or lacking elsewhere. In some features they resemble the much more abundant, and more widely dispersed, lakes of central Ontario, as described by Wilson; in one respect they are sharply contrasted with them.

Wilson describes the Ontario district as characterized by a prominent cuesta front at the north edge of the Paleozoic limestones,

overlooking the Precambrian areas to the northward. The drainage is to the southwest and passes from the Precambrian into the Paleozoic limestone country, the streams deeply notching the cuesta front as they pass into it. Of the lakes he says: "In most cases the upper parts of these valleys, near where they pass through the cuesta front, form the basins of long, narrow lakes. The water seems in some cases to be held back by a drift dam, which partly blocks the lower part of the valley. Certainly in some cases, in all probability in most cases, the present lake basin is a rock basin and the existence of the present lake is due either to warping or possibly to differential erosion by ice.¹"

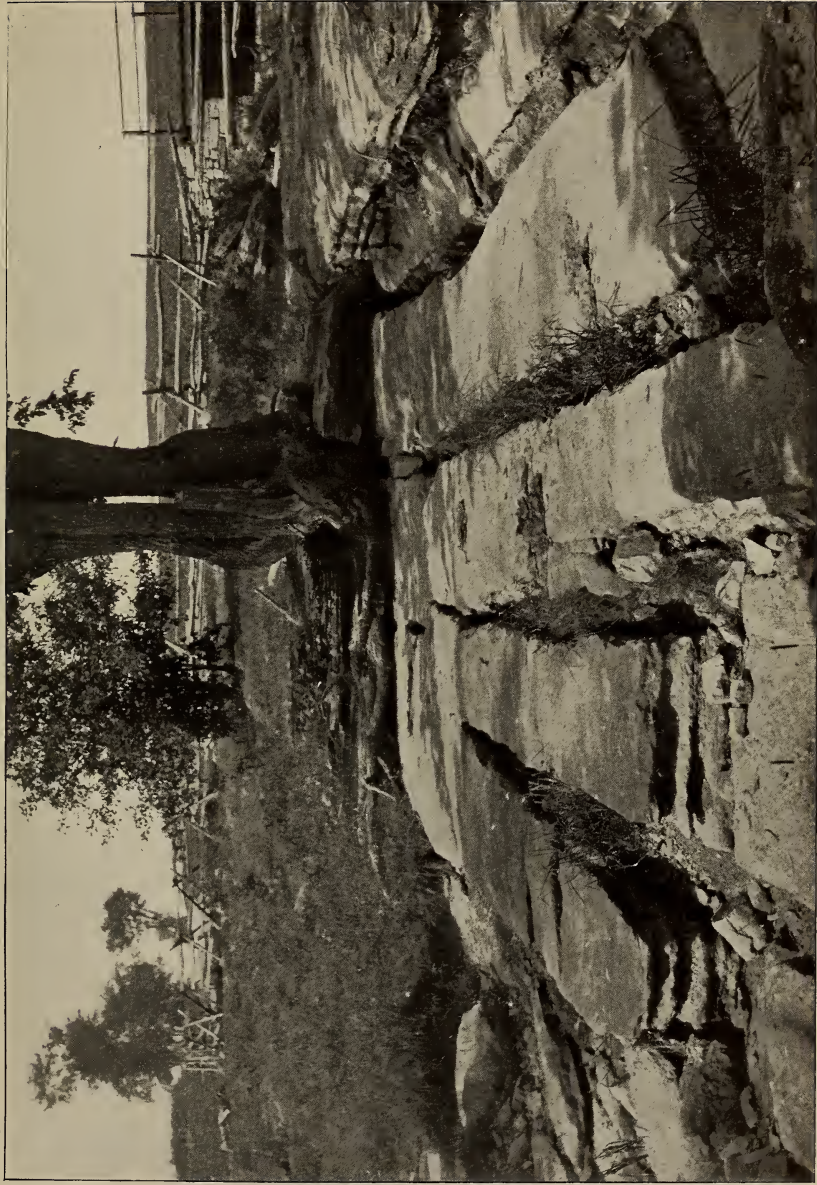
In this district of Wilson's the Potsdam and Theresa formations are absent, the Pamelia, or Lowville, resting on the Precambrian, forming a single cuesta front that is more prominent than those in our district. The lakes on the Alexandria sheet have their beds either on Precambrian or on Potsdam, and the limestone front is more or less remote. They nestle in the extreme upper portions of the valley heads on the north side of the divide which runs through the region, and has just been described. They are in the extreme upper portions of the valleys of north-flowing streams, instead of occupying a special position in the valleys of southerly streams, as in the case of the Ontarian lakes, and in this lies their chief difference from those. Hyde lake, in the northern portion of the Theresa sheet, conforms more nearly to the Ontarian type, though in Potsdam instead of Precambrian, and Perch lake seems the shallow remnant of another lake of similar type. The Alexandrian lakes, however, differ as specified, and herein lies also the reason for their localization. The old divide runs into higher ground passing eastward, and the relations of the rocks shift. The streams there rise in the Precambrian and run northward into the Paleozoic rocks of the St Lawrence valley, while our lake valleys here commence in Potsdam and run north into Precambrian.

Most of the lakes seem to be in rock basins, Crystal, Sixberry and Millsite certainly are, and Butterfield probably is. Crystal lake is entirely in Potsdam though its bed may be on the Precambrian, and is walled by high and continuous sandstone cliffs, with the sharply cut valley head but a short distance back from the lake margin [pl. 34]. Sixberry, Millsite and Butterfield are partly walled by Potsdam, with characteristic cliffs, and with valley heads cut in Potsdam, but with their beds in Precambrian [pl. 54]. The beds of the two latter are in large part in Grenville limestone. Six-

¹ *Op. cit.* p. 217.



Head of Crystal lake, 2½ miles south of Redwood, looking north down the lake. Cliff of Potsdam sandstone, characteristic basin wall, seen at right. Compare plate 51. H. L. Fairchild, photo, 1908



Bared surface of Tribes Hill limestone, 1 mile west of Lafargeville and close to the point from which plate 15 was taken. The joints run *n. 70° e.* and the view shows that some solution takes place along them even in this rock; in fact the stream is now flowing below ground and breaks out as a large spring at the base of the rock wall shown in plate 15. H. P. Cushing, photo, 1908

berry is surrounded by quartzite and granite and there is no known evidence of limestone in the bed.

Whether these basins were dug out by ice, or have resulted from warping, we are unable to say. In either case we can not see why no lake was formed in the valley which heads at Browns Corners, and is of identical type with the others. The extreme head of a valley up which the ice was moving would seem an unlikely place for it to dig. Solution of limestone may have aided in the formation of some of the basins. Though we are unable to account for them to our satisfaction, their localization seems to us unquestionably due to the localization of the especial type of valley heads in which they occur.

Underground drainage

It has previously been shown how, in the more soluble limestones of the district, chiefly the Black River and upper Lowville, rain water widens the joint cracks by solution, and much of the surface water of the district passes down through these fissures to underground flow [pl. 26 and 27]. The Leray limestone is more soluble than the Lowville and the chief underground drainage of the region is in Leray districts, the underground waters running along on the upper surface of the Lowville, slowly enlarging their channels by solution. But there are also underground waters in the Lowville the upper beds of which are more soluble than those beneath. Even in the Theresa formation similar action is at times seen. In plate 35 may be seen bared Theresa surfaces in the bed of a brook, with joints considerably enlarged by solution, sufficiently so to allow the water of the creek to entirely disappear through them, to emerge a few yards away at the base of the cliff shown in plate 15, the cliff being part of the rock wall of a somewhat filled Tertiary valley, that of the Chaumont river. During the spring floods the underground channel can not care for the entire flow, and part of it remains at the surface, flowing over the rock exposed in the view. In the Leray and Watertown limestone districts are many stream beds of bare rock, totally dry throughout the summer, with their waters underground, but showing plainly the incapacity of the underground channel to care for flood waters, which flow in part at the surface, and keep the beds thoroughly washed out. Examples of such are the creek coming into the Black river from the south at Felts Mills (southeast corner of Theresa sheet), and the bed of Philomel creek near Brownville. Much underground water comes into the Black river, all across the district.

With enlargement of the underground tunnel the roof tends to cave in, at first where thinnest, followed by gradual lengthening. In most cases the cover is thinnest toward the stream mouth and caving in begins there and works slowly upstream. In the case of the creek at Felts Mills, just referred to, the map shows Lowville limestone in its bed for a half mile above its mouth, beyond which the Leray forms the bed rock. In the Lowville for part of its course the stream is above ground, and the point where the formational contact crosses the stream marks the point of emergence from underground, and the slow upstream working of the roof cave in. In plate 36 is a rather unsatisfactory view of the caved roof of a small stream, unsatisfactory because no position of the camera which looked upstream could be obtained, and we are here merely looking across from one bank to the other, with the nearer bank somewhat hiding the view of the opposite one. The stream is a small one, fed by the underground waters of a Leray promontory of no great extent, but its waters emerge from well down in the Lowville, (which alone appears in the plate) and can be seen in the extreme lower left-hand corner. The caving extends many yards upstream and amounts to some 20 feet in height at the lower end.

Plate 37 gives an interesting illustration, on a small scale, of another feature. The view shows a Lowville platform, surfaced by a resistant layer of somewhat less solubility, and, on the right, the point of emergence of a small, wet weather stream, flowing in a shallow underground channel in the more soluble material underneath. The stream course then curves across the foreground and passes backward and toward the left, its course margined by the projecting edge of the hard layer, which has otherwise been removed from the channel with the exception of the fragment left as a tiny "natural bridge" on the left.

As already pointed out by Ruedemann, in his account of the Lowville inliers in the Leray limestone, very interesting underground features are shown in the Perch river valley about Limerick (Clayton sheet). The rock structure there seems to us to be anticlinal, with the Leray limestone at Limerick marking the site of a sag, and the Lowville inlier, just south, the site of a dome of the anticlinal crest. North of Limerick increased southerly dip transfers the stream from the Lowville to the Leray horizon, south of it diminished south dip transfers the stream back to the Lowville again, the point of transfer being marked by a fall [pl. 23] as is the rule in the streams of the region when passing



Caved-in roof of a small underground stream in Lowville limestone, nearly 3 miles west of Sanford Corners, Theresa quadrangle, looking north. A good position for the camera could not be obtained so that the view does not exhibit the conditions clearly. The issuing stream shows in the lower left-hand corner. H. P. Cushing, photo, 1907



A less soluble, overlying a more soluble layer of Lowville limestone. A small cavern in the latter and covered by the former shows on the right, and a miniature "natural bridge" left in the wearing away of both shows on the left; 3 miles northwest of Sanford Corners. H. P. Cushing, photo, 1907



Perch river emerging from beneath a limestone wall after flowing underground for $\frac{1}{4}$ mile. Note the sunken appearance of the limestone of the wall. H. P. Cushing, photo, 1908

from the Leray to the Lowville. But when increased south dip brings down the Leray again, at the south end of the inlier, the formation appears as a wall across the valley, and the stream follows the Lowville underground, though its course is marked by a depression in the surface of the Leray above. After flowing underground a short distance the river reappears at the surface, or more strictly the surface comes down to the river level, owing to caving down and removal of the Leray. In plate 38 this emergence of the stream is shown. It quickly passes again underground. The process seems definitely the enlargement of an underground channel by solution until the roof becomes unsupported, sags and caves in where thinnest, with succeeding gradual extension of the caving in process, both up and down stream. About Limerick the Leray limestone forming the stream walls is shown in all stages of disturbance due to this undermining process. The view in plate 23 shows the process in an early stage, and that in plate 39 in a much more advanced stage, the Leray here being in a condition for which Ruedemann's term of "scrambled" is so absolutely applicable, that we can not refrain from utilizing it.

In plate 40, a view of the stream above the falls at Limerick, we seem to have a direct exposition of what the character of the stream is when underground. It seems distinctly a solution, not a corrasion, channel following the joints in beautiful, zigzag fashion. The chief part of the course shown in the view is on a northwest joint, but in the foreground, and also in the background, it is along a set of north joints. It seems to us highly probable that the stream was formerly underground here. Unquestionably the channel is due to solution along, and guided by, the joints. The locality is so suggestive that it is a pity a longer portion of the stream's course can not be photographed. A contrasting view, that of plate 41, shows a limestone surface (the same limestone) corraded and etched by surface solution and wear.

The influence of the low folds in the Paleozoic rocks in causing falls in the streams which more or less directly flow down the dip, has just been noted in the case of the fall at Limerick. The course of the Black river across the south margin of the map furnishes a fine illustration of a stream whose fall is precisely that of the dip, and along which, owing to variations in the amount of dip, repeated falls occur over identically the same rock horizon. The river here has cut a shallow valley in rock, in postglacial times, and the chief falls in this part of its course are at Felts Mills, Black

River village, Watertown, Brownville and Dexter; and at each locality use is made of the water power. Every one of the falls is over the massive Leray limestone into the Lowville beneath, as well shown in Ulrich's excellent panoramic view of the main fall at Watertown [pl. 42]. There are minor falls of the same type between the chief localities. Below the fall the river flows along in the Lowville until the steepened dip on the western limb of an anticlinal fold carries the overlying Leray limestone down to, and beneath, the water surface, forming the bottom of a shallow, synclinal trough [see pl. 28 for such steepened dip at Brownville]. In this the dip flattens, and then becomes low east, bringing the Leray base back to stream level, and giving opportunity for development of the fall as the water passes on to the less resistant Lowville beneath, the fall so begun slowly cutting back up stream with gradual increase in height. Down stream the river remains on the Lowville under the general low anticlinal arch, until the drop of its western limb again puts the Leray limestone beneath the river level, with repetition of the previous conditions and another fall where the limestone comes back again. Because of the westerly dip the western limb of the anticlines is steeper than the eastern, and the river cuts the bottom of each syncline at substantially the same horizon. The diagram [fig. 12] will illustrate the conditions, which are somewhat exceptional, better than can be done verbally.

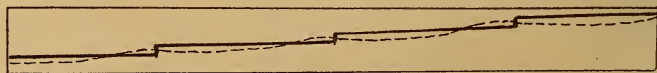


Fig. 12 Diagram illustrating the rock structure which gives rise to the successive falls in the Black river, the heavy line representing the river bed with three falls, and the sinuous dotted line the base of the Leray limestone, showing how, due to the folding each fall is over the same rock horizon as its predecessor. Dips and fall of river much exaggerated

PLEISTOCENE GEOLOGY¹

History

A brief outline of the Pleistocene history and its relation to the earlier time is given on pages 23 and 24.

At least three distinct episodes are recognized in the recent geologic history of our region. These are (1) burial under the ice sheet, (2) burial under standing waters, (3) renewal of the exposure to the atmosphere.

Glaciation. The glacial theory has long since passed into the category of accepted fact. That our area has been subjected to

¹ By H. L. Fairchild.

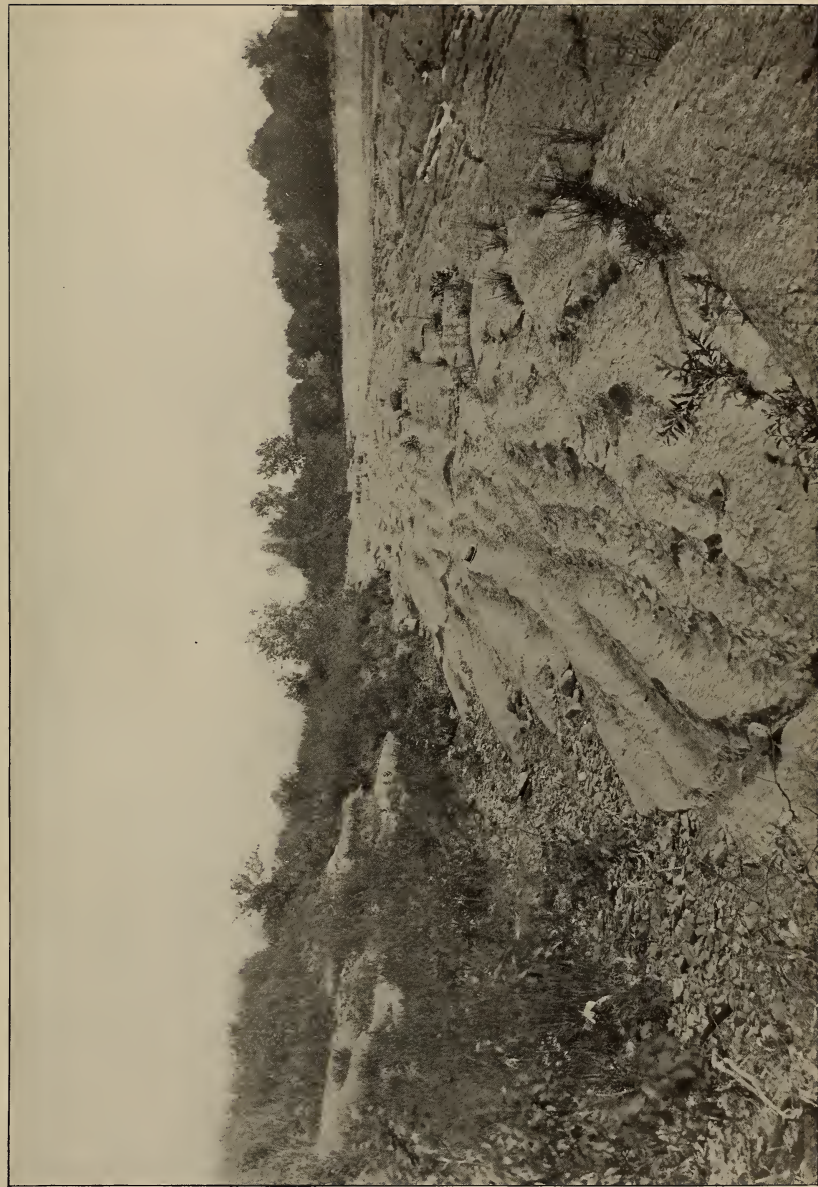


Leray limestone overlying Lowville, banks of Perch river at Limerick, near the point at which plate 21 was taken. Shows the Leray breaking up and working down the bank, owing largely to solution of the Lowville beneath. H. P. Cushing, photo, 1908

Plate 40



Perch river above the falls at Limerick, Clayton quadrangle [*see* pl. 23]. The rock is Leray limestone and the stream course here follows enlarged joint cracks, first one set and then another. The enlargement seems wholly owing to solution and likely was formerly an underground channel. Looking northwest and upstream. E. O. Ulrich, photo, 1908



Stream erosion of Leray limestone, west edge of Watertown; north bank of Black river. Looking south. H. L. Fairchild, photo, 1908

Plate 42



Fall in the Black river at Watertown; river falling over the lower bed of the Leray limestone into the Lowville beneath. E. O. Ulrich, photo, 1908

the rubbing and grinding action of a continental ice sheet has long been recognized, and now it seems almost certain that instead of only one there have been several ice invasions of the territory. Students of glaciation find evidences of multiple glaciation in the Mississippi basin, in Canada, in New England and in Pennsylvania. It seems impossible that New York should have escaped occupation by ice sheets that buried surrounding territory. In the Mississippi basin the glacial epochs have been named as follows, in order of time: Jerseyan, Kansan, Illinoian, Iowan, early Wisconsin and later Wisconsin. While there is some doubt as to the validity of the Iowan yet the multiplicity of the glacial invasions seems to be a fact. The intervals between the glacial stages, the interglacial epochs, are believed to have been long periods of temperate climate. It seems possible that our present time of release from glacial conditions may be only a warm interval between the latest ice invasion and another invasion to come in the near (geologically) future.

This matter of multiplicity of ice invasions is here emphasized for the reason that the glacial features of our district seem to require for satisfactory explanation the work of more than a single ice sheet. The glacial phenomena will be described in proper order.

Submergence. *Lake Iroquois.* As the latest glacier waned and the front receded and moved northward the ice was replaced by a body of water, the glacial lake Iroquois. This great lake, held in the Ontario basin by the ice barrier blocking the St Lawrence valley, and with its outlet at Rome to the Mohawk-Hudson, laved the receding ice front continuously over all the area described in this paper. An important effect of this condition, which the reader should hold in mind, is that all the materials left by the waning ice were laid down beneath the Iroquois waters, and are consequently more or less modified by the water action.

The present altitude of the Iroquois beach east of Watertown is 733 feet. The only point on the entire area covered in this paper which is sufficiently elevated to reach the Iroquois plane is the extreme southeast corner of the area, as shown at the bottom of the Theresa sheet, [pl. 44]. Here the nose of the Rutland promontory brings the 800 foot contour on the map and the Iroquois shore line is a steep cliff on the limestone scarp. On account of the postglacial uplift and northward tilting of the region the Iroquois plane, and all later water planes, rise to the north. On the parallel of Redwood it is estimated that the Iroquois water surface was about 800 feet, and at Chippewa Bay toward 900 feet. The depth of water over

the plain at Watertown was 200–250 feet, at Lafargeville about 350 feet, and over the plains at Chippewa Bay about 550 feet.

Eventually the ice barrier weakened in the St Lawrence valley and the Iroquois waters found a new outlet north of the Adirondacks which was lower (at that time) than the old outlet south of the Adirondacks by the Mohawk valley. One point of escape was the "Covey Hill gulf," precisely on the international boundary between New York and Canada, about 4 miles northeast of Clinton Mills.¹ The Covey gulf is a great V-shaped gorge in hard Potsdam sandstone, leading north of east, and it carried the waters of the second stage of Iroquois, or the Hypo-iroquois, over to some lower level in the Champlain basin. From aneroid measurements it is estimated that the altitude of the head of the gulf is about 850 feet, or perhaps somewhat higher, but when the gulf was made the district was at least 460 feet lower than it is today, and must have been lower than the Rome outlet, which is now 430 feet. It appears that the Covey gulf outlet was not much lower than the Rome outlet, perhaps 50 feet and possibly 100 feet. It might seem as if the Covey gulf outlet represented sufficient length of time for the lake waters at that level to produce recognizable features along favorable stretches of the shore line, and such may yet be found. Dr Gilbert has suggested that possibly the Covey gulf was chiefly cut by a more ancient glacial outflow and that the Hypo-iroquois may have done little work beyond clearing out the old gorge.

As the ice front melted back this second stage of the glacial waters of the Ontario basin found yet lower escape along the north side of Covey hill, between the ice wall and the rock slope. This third phase of the Iroquois waters must have been short-lived, with rapidly falling levels, the river flow only terracing the sandstone slope. It is thought that the final effect of this down-draining of the glacial waters was to bring them into confluence with the oceanic waters which then occupied the Champlain basin and are called the Champlain (Woodworth's Hochelagan) sea. The supposed extension of the sea-level waters into the Ontario basin is known as Gilbert gulf.²

Gilbert gulf. If our present conception of the history is correct the sea-level waters covered nearly all the territory comprised in our five quadrangles. On the north slope of Covey hill the Champlain beaches have an altitude of at least 460 feet, which is the measure of the amount of land uplift in

¹ For description and illustrations of this outlet see paper by J. B. Woodworth, *Ancient Water Levels*. N. Y. State Mus. Bul. 84. Ebenezer Emmons and G. K. Gilbert had noted the feature.

² *Gilbert Gulf (Marine Waters in Ontario Basin)*. Fairchild, H. L. *Geol. Soc. Am. Bul.* 17:712-18.

that district since the ice left that locality. The Gilbert plane declines to the south and southwest and on the south border of our area the beaches are 390 feet [pl. 45]. North of Lafargeville [pl. 46] strong beaches lie at 440 feet, and 2 miles southeast of Redwood a bar is found at 450 feet altitude [pl. 47].

It has not seemed practicable to make maps for this writing to show all the Gilbert shore lines of the area, but the strongest shore features are indicated on the maps, plates 45-47. These are wave-built bars and spits and wave-washed limestones. Some of these features are shown in the halftones, plates 48-53. The southeast portion of our area, being the southeast diagonal half of the Theresa sheet, was mostly above the Gilbert waters. The submerged parts are such as lie below 400 feet at the south edge of the sheet and below 440 feet at the north edge. It will be seen that this is the low ground north and northeast of Brownville, the valley of Perch river, the low ground about Theresa and the valley of Indian river. All the rest of the region was under the full Gilbert level except the three limestone hills northwest of Dexter; the limestone plateau between Stone Mills, Depauville and Lafargeville; the limestone plateaus north of Depauville; the boulder-kame hill 2 miles north of St Lawrence corners, known as the "Hogback"; and the group of boulder-moraine hills north of Lafargeville; one being cut by the edge of the Theresa sheet. These areas which received wave action so as to leave beach records are mostly shown in the plates 45, 46 and 48.

While all surfaces between the highest Iroquois and the Gilbert planes have been wave-swept by the subsiding waters, and many patches of bared rocks are found at various levels, no beach phenomena have been noted between the two planes. All the high level shoreline features in our district are confidently referred to the sea-level waters.¹

¹ Since this paper has been in type Prof. George H. Chadwick discovered heavy beaches and deltas of Lake Iroquois in St Lawrence county, and also extensive deltas inferior to the Iroquois plane and of uncertain relationship. In August 1910 we examined these features and carried the study north-eastward into Canada.

The Iroquois plane is now definitely known at several points, the farthest east being at Chateaugay with altitude 975 feet. On the international boundary at Covey hill the full-height plane is not much above 1000 feet. The head of Covey gulf, the outlet of the lower or Second Iroquois, is about 980 feet.

A recent survey on the Canadian side of the boundary gives us precise altitudes for the sea-level beaches (Gilbert gulf), which have at Covey Hill post office a height of a least 523 feet.

These altitudes are entirely consistent with the figures and facts relating to the Iroquois and Gilbert gulf water planes given in this report.

From the Iroquois to the Gilbert levels the waters fell with comparative rapidity by the removal of the ice dam. The apparent lowering of the Gilbert waters was on the contrary by the very slow uplifting of the land out of the sea-level waters. This rising of the land must have been so slow as to give opportunity to the waves at all minor levels to produce shore line phenomena, and many such are found. However, such proofs of the presence of standing waters are missing over long stretches of even the summit plane, which emphasizes the well recognized fact that absence of clear wave work does not necessarily prove the absence of standing waters.

But while beach phenomena may be lacking or weak over wide stretches we find other evidences of the waters. Either by the lowering of the Iroquois waters over the higher ground or by the lifting of the lower ground through the Gilbert waters all the land surfaces have been brought into the zone of wave action and subjected to erosion or deposition by the agitated waters. In consequence the steep slopes, the projecting rock masses, tables and knobs, have been more or less cleared of their drift and specially of the finer material, which has been shifted to lower levels. The broader plateaus and plains have been smoothed and the lower grounds, valleys, basins and hollows, have been more or less filled or silted with the detritus, sand or clay, washed from the higher ground. This action explains two striking characters of the region, the areas of bare rocks and the silt-filled basins, which will be discussed later.

Conclusive proof that the lower waters were confluent with the sea would be the finding of marine fossils. Such have not yet been found in the Ontario basin, though they are abundant in the Champlain and St Lawrence valleys, and marine shells have been found as far west as Ogdensburg.

Atmospheric erosion. The whole region, above the Ontario level, has long been subjected to a renewal of the atmospheric agencies. The length of time is unknown, but is not equal for all the area. For the lower plains, near the present lake, the time must somewhat exceed the life of Ontario; while for the higher ground, above the Gilbert levels, the time must cover not only the life of Ontario but also that of Gilbert gulf. If we estimate the life of each of these water bodies as 10,000 years it may give some fair conception of the duration in years. For lands above the reach of Lake Iroquois its length of life must be added to the time of exposure, at least another 10,000 years. It is likely that these figures are too small rather than too large.

Physiography

Glacial diversion of the Black river. The history of the Black river is not only the most interesting problem connected with the evolution of the physiography of the region but specially important as it may supply the key to Tertiary drainage of the entire area.

In only the middle portion of its course has the present Black river any pronounced valley. The headwaters and upper section, about 30 miles long, lie on the crystallines of the southwest slope of the Adirondacks, with no conspicuous valley. The lower section, below Carthage, has only a shallow postglacial channel. The great valley begins at about Forestport and extends northwest to Carthage, a distance of more than 40 miles, and steadily deepens and widens northward. At Glenfield or Lowville, near the middle part of the valley, the altitude of the river is 740 feet, while the great ridge on the west, separating this valley from the Ontario, rises to 2000 feet, and the breadth of the valley is at least 10 miles on the 1300 foot contour.

Former writers have regarded the Black river as the trunk stream of the early drainage which headed the Ontario valley.¹ It appears to the writer that that view is a mistake and that quite the opposite is the fact, that the Black river was the headwater of the St Lawrence drainage, at least for New York State.

Plate 43 shows the present hydrography of the region and the divide between northward and southward streams of the Ontario-St Lawrence valley. Plates 44 and 47 show portions of the divide on the larger scale of the topographic sheets. On plate 43 the heavy, broken line south of the Black river marks what was the preglacial divide between Ontario and St Lawrence drainage before the Black river was forced by the interference of the ice sheet across the divide. The light, continuous line indicates the present and shifted divide. It is apparent that below Great Bend the river has peculiar and anomalous relationship, and that the divide leading east up the Adirondacks slope is newly established.

In discussion of this problem the theoretic evolution of the drainage will be considered first and then the recent history and the present features.

The Black valley was initiated and developed, at least as early as the Tertiary uplift, along the contact or overlap of the Ordovician sedimentaries on the ancient crystallines. The west wall of the

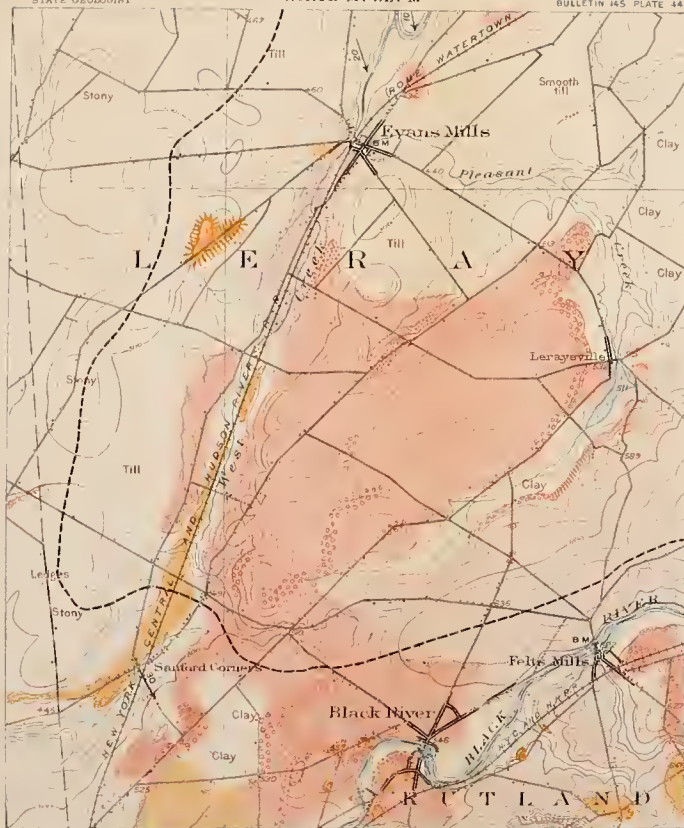
¹ Specially the paper by A. W. G. Wilson, Trent River System and the St Lawrence Outlet, Geol. Soc. Am. Bul. 15:211-42. Pages 236-38 refer to our district. With the entire article excepting the point of the Black river relationship we are in hearty accord.

great valley shows all the strata from the Pamela to the Oswego sandstone. The east wall of Precambrian rocks is deeply buried under sand plains or delta deposits accumulated in glacial waters.¹ The axis of the deepening and north leading valley migrated westward, down the slope of the basal crystallines and against the outcrop of the sediments.

The great ridge dividing the Black and Ontario valleys now terminates abruptly in the Rutland promontory with a limestone scarp about 400 feet high. The point of this promontory is shown on the lower edge of plate 44, south of Felts Mills and Black River villages. A glance at the Watertown sheet will show how the river below Felts Mills clings to the foot of the scarp. A moment's thought will make it evident that these thick limestones did not originally end here, but must have extended far north, overlying the district toward the St. Lawrence. It seems perfectly evident that the stratigraphic relations and the erosional conditions which produced the Black valley above Carthage must once have extended much farther northward, and the Tertiary river probably had its course northward along what is now the east slope of the St. Lawrence valley, in continuation of the Forestport-Carthage valley. The problem is therefore narrowed to the question of the time of the removal of the Trenton limestones north of the Rutland promontory, and the date of the diversion of the river from its northward into its westward course.

A singular physiographic feature of the region is the northward or rather northeastward direction of all the heavy streams north of the Black river. These all flow along parallel with the St. Lawrence, and in some sections at even lower levels. In normal stream development the tributaries should flow toward the trunk stream. The Indian, Oswegatchie, Grass, Raquette and St. Regis are more or less independent of the St. Lawrence and are not normal tributaries. Their courses have probably been modified, straightened and their parallelism emphasized by repeated glaciation, but the latest ice erosion has certainly been insufficient to produce such channels. Their direction is in precise opposition to the glacial effect and also in opposition to the postglacial uplift of the region. It is in harmony with and in continuation of the Black valley, curving eastward around the uplifted mass of the Adirondacks. It seems altogether likely that these stream courses were developed by north leading drainage having practically the same stratigraphic

¹ See a paper by the writer, *Glacial Waters of the Black and Mohawk Valleys*. N. Y. State Mus. Bul. *In press*.



LEGEND

Marginal Drift, Moraine



Ordinary stoniness



Very stony



Boulder ridge



Marginal Drift, Kame



sand arcs



Sand knolls



Lake Iroquois Features



Cliff shoreline



Delta sandplain



Barred rock

Gilbert Gulf Features



Sandplain, delta (?)

Glacial Striae



Numerals indicate degrees from meridian

Drainage Divide



Between northeast and southwest flow.



relation as that which initiated the Black valley. The only features which are not in harmony with the above theory are the southward course of a section of the Indian river, above Evans Mills, and of the Oswegatchie above Oxbow. These are probably due to glacial diversion, similar to that of the Black below Great Bend, but for better knowledge we must await the topographic sheets.

Professor Cushing suggests that north from Felts Mills the pre-glacial divide might have swung west from the present course, passing south of Perch lake, through Depauville and south of St Lawrence corners. The wider valley of the Chaumont north of Depauville and the northward course of French creek favor this view. It is quite possible that Prewisconsin glacial erosion has caused a northward migration of the portion of the divide that was transverse to the ice flow, but the latest ice work seems to have been too weak. We may not appeal to forced stream flow during the last ice recession, as the region was then buried under Iroquois waters. The northward uptilting of the area tends of course to divert sluggish drainage into southward flow, but alone this could not be a very effective factor.

Passing now to certain specific data and features connected with very recent history, the reader should note again the intimate relation and parallelism of Black river to its northward flowing neighbors [pl. 43], after which a glance at plate 44 will show the cause of the separation and the character of the barrier. At Great Bend and Felts Mills the river has cut into the south side of its own delta, that was built in Lake Iroquois. Along much of that stretch rock is seen in the bed of the river, beneath the steep wall of the delta deposits. North of the delta the ground is 100 feet or more lower than the river, and all draining northward. At Felts Mills the river has an altitude of 580 feet, while only $1\frac{1}{2}$ miles north, and simply across the delta divide, is Pleasant creek, a tributary of Indian river, at only 520 feet altitude. The fall from Black river to Indian river by Pleasant creek is 200 feet in about 6 miles. Further up stream, at Great Bend the river has a large meander in the delta and the facility for northward flow may be even better than at Felts Mills, but the topographic survey has not covered the district.

The suggestion is natural that possibly a rock barrier is buried under the delta, which would be an effective barrier to north escape of the river if the delta were removed. Fortunately we have specific data. Mr F. A. Hinds, the well known hydraulic engineer of Watertown, has pointed out the important fact that the drainage

of the great sponge of sand plain, on which is located the military camp, is not into the Black river but north into the Indian river.¹ Along the north side of the sand plain huge springs gush out along the contact with the impervious drift, while such are entirely wanting on the Black river side. It is certain, therefore, that if the delta at Felts Mills and Black River were not there the river would plunge northward. It is equally certain that before the ice invasion, and the deposition of the delta and moraine barrier, the river did flow northward. The only condition which could produce southward flow would be a northward uplift 20 or 30 feet per mile greater than we have today, which is extremely unlikely for this district. As long as any of the St Lawrence valley drainage passed north the Black river went with it.

The westward course of the Black river from Great Bend is due to glacial diversion. The river is on rock and with no proper valley. It is in a postglacial channel. Moreover, there is no south leading valley in the Watertown district sufficient for a large river. If there were the Black would be in it today as there is no heavy drift barrier to block drainage in the district south of Watertown.

The later history is quite clear. During not only the advance and retreat of the latest ice sheet but probably that of earlier ice sheets the Black valley high-level waters were forced westward and southward around the Rutland promontory. High on the slopes at Copen-

¹ Extracted from report of Frank A. Hinds to the Water Board of the City of Watertown, June 29, 1908.

. . . the entire country slopes toward the north and west and away from the bank of the river which is the highest part.

The Pine Plains is a sheet of very clean sand from 50 to 75 feet thick and covering an area of from 25 to 40 square miles. The sand is so porous that all the rainfall sinks directly into it and forms a natural reservoir at the bottom. This ground water has a slow movement in the direction of the slope but does not become exhausted during the dry season as the constant character of the springs at its edge proves.

While the water of the river opposite the (U. S. military) camp is 100 feet below the surface of the plains, there is an impervious bed of clay and rock underlying the sand which is from 30 to 50 feet above the river. This clay may be seen in many places along the bank, though in others the sand has run down and covered it over. Five miles to the west the sand plateau stops and the clay substratum continues as the surface soil of the country; but here it is 100 feet lower than where it commences at the river brink under the camp.

This northwesterly slope of the subsoil determines the direction or flow of the underground water and accounts for the fact that there are but few and comparatively small springs flowing into the Black river from under the plains, while those along the western border of the sand are more copious and gather into several creeks or brooks of noticeable magnitude which flow westerly into the Indian river. The few springs along the Black river bank are where the underground water spills over the easterly upper edge of the clay stratum, but they are comparatively few and small . . . the water which emanates from under the Pine Plains does not get into the Black river to any extent worthy of attention.

[Faint, illegible handwriting on a lined page]



- LEGEND**
- Gilbert Gulf Features**
- Bars and spits
 - Cliff
 - Hypothetic shorelines
 - Sandplains/delta (?)
 - Bared rock
- Glacial Striae**
- Numerals indicate degrees from meridian

Parts of Clayton and Theresa sheets

PLEISTOCENE FEATURES: CHAUMONT-BROWNVILLE DISTRICT

H. L. Fairchild, 1909

hagen and Champion are the glacial channels [see footnote p. 142]. The Rutland Hollow is a capacious valley cut obliquely across the nose of the promontory, parallel in direction with both higher and lower glacial channels of Black valley outflow, and was undoubtedly given its form and dimensions by glacial drainage. When the Black valley waters were lowered into Lake Iroquois the Black river built its delta in the lake northwest of Carthage, partly banked against heavy moraine. When Lake Iroquois was lowered into Gilbert gulf the Black river found its ancient course obstructed by the delta and moraine deposits and was compelled to follow around the rock promontory in the path of the stronger shore currents in the lake. West of Watertown the river dropped its detritus in the sea-level waters (Gilbert gulf), and when these waters were lowered by the land uplift the river pursued its chance course over the rock toward the retreating water body.

To epitomize: It seems certain that the earliest drainage which we can locate must have been along the weak zone of the overlap of the sedimentary rocks on the Precambric, in north and north-east continuation of the Black valley. Preceding the latest ice invasion the Black river probably flowed north. Just what may have occurred during the Tertiary uplift and the earlier Pleistocene we do not know. It is possible that there are unsuspected elements in that long history, but there is no discovered reason for any preglacial southward drainage across the divide as mapped in plate 43. The really uncertain factor is the glaciation earlier than the Wisconsin epoch. The writer is inclined to credit to glaciation earlier than the Wisconsin considerable influence in producing the parallelism of the rock forms and the drainage lines along the St Lawrence depression; and the bluntness and roundness of the Rutland promontory; and the cutting of the Rutland Hollow.

Topographic features. *Parallelism.* The topographic elements of the area have a conspicuous parallelism, about northeast and southwest, in accordance with the St Lawrence valley and river. On the Clayton and Theresa sheets this shows clearly in the stream and valley courses and in the trend of the plateaus and rock hills. On the Alexandria and Grindstone sheets the parallelism appears in the elongation of the rock knobs and the form of the lakes and the islands in the river. This character prevails down the valley far beyond our district, as shown by the river courses which instead of flowing directly to the St Lawrence follow along in parallel courses [pl. 43].

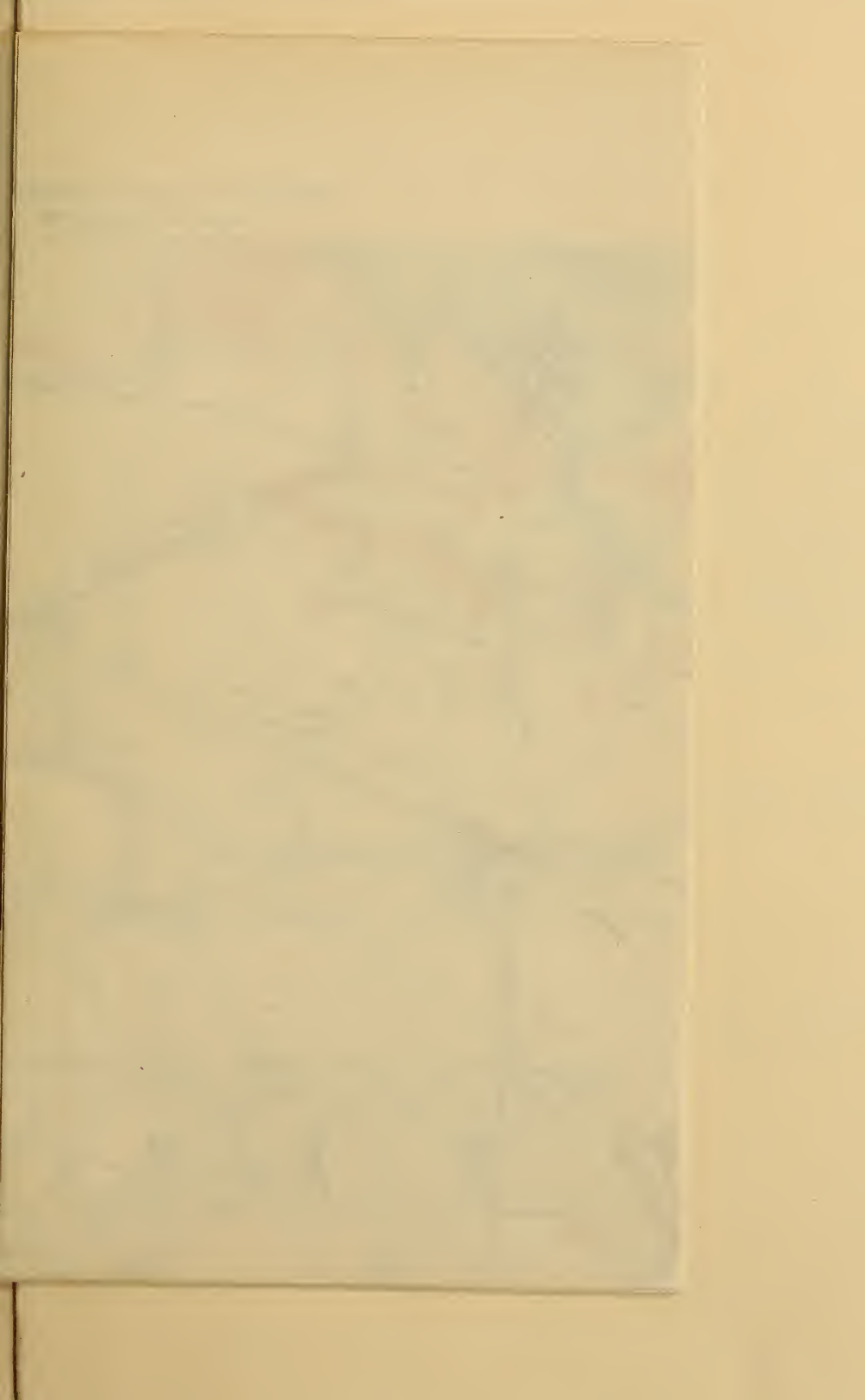
The genesis of this prevailing orientation probably involves factors which cover the entire geologic history of the region. In an earlier chapter Professor Cushing has shown that during the time of the earliest sedimentation in the region there was alternately a tipping to the northeast and the southwest, the fulcrum of motion lying across our district, initiating what is called the Frontenac axis [p. 95]. The broad depression of the valley is thought to be partly the result of sagging, accompanied by jointing, one main trend of joints having fair agreement with the trend of the valley. Cushing also shows that some slight folding occurred in Paleozoic time and stronger folding in Precambrian time which probably had some directive influence on the drainage [p. 108-115].

The larger existing features and general stream directions were developed during Tertiary time under subatmospheric erosion. During Pleistocene time the St Lawrence valley, being closely in line with the spreading flow of the ice sheet over the region, served as a trough for the advancing and the waning ice lobes. We do not know the number of ice invasions but it seems quite certain that the latest, or Wisconsin, ice sheet was preceded by others of probably greater effectiveness in erosion. The striking parallelism of the minor features of the topography is probably due in some degree to repeated glaciation, the alternation of ice flow of the glacial epochs and the stream erosion of the interglacial epochs mutually assisting or guiding each other.

Dominant types. The topographic features in the sedimentary rocks are naturally an expression largely of the stratigraphic characters. This has already been discussed in a former chapter by Cushing [p. 121-136]. In the present connection we have to consider the topography in its relation to the glacial and glacio-aqueous history.

Leaving out of account for the present the localized and scanty moraine deposits, we may distinguish two dominant types of the surface relief in the area, (1) the rounded rock hills or knobs of rather striking relief in the northern part of the area, in the district of Potsdam and Precambrian rocks, and (2) the broad level stretches which characterize the southern half of the area, where the rocks are well stratified.

Rock knobs. In the northern part of the area, covered by the Grindstone and Alexandria sheets and the northeast part of the Theresa sheet, the crystalline rocks and the lower Potsdam appear commonly in the form of knobs or bosses, singly or in clusters and chains, as illustrated in plates 6 and 7. Cushing has shown [p. 54]





LEGEND

Marginal Drift, Moraine



ordinary moraine



Very stony



Boulder ridges

Marginal Drift, Kame



Sand areas



Boulder kames

Glacial Stream Work



Eskers

Gilbert Gull Features



Bars and spits



Cliffs

Hypothetic shoreline



Bared rock

Glacial Striae



Numerals indicate degrees from meridian

that the knobby surface of the crystallines is the immensely ancient erosion surface of the Precambric land area, which had been buried under Potsdam sediments and only recently uncovered. Ice erosion seems to have had very little influence in shaping the surface, merely rounding and smoothing the knobs.

The major axes of the knobs are roughly parallel with the valley and the ice movement, but the relation to the latter is mostly casual and not genetic. The struck or northwest side commonly shows more erosion, but frequently the difference is not evident. As a rule the crystallines have not retained their striae and polish as well as the Potsdam sandstones.

Plains of erosion. The broad plains, either rock or rock floored, are regarded as the product of long eras of atmospheric erosion with later glacial planing and a finishing touch of wave smoothing. They are found in districts where the sedimentary rocks are persistent in considerable thickness so as to cover the Precambric and the lower and irregular Potsdam. Broad tracts of this class consisting of upper Potsdam occur south of Chippewa Bay and toward Alexandria Bay. Theresa dolomite forms the plain north of Chippewa Bay and covers large areas on the parallel of Plessis and Clayton. South of the parallel of Lafargeville the plains and plateaus are limestones.

The earlier ice sheets seem to have lifted or plucked away the weathered and weak superficial layers of these stratified rocks down to some firm, less jointed and more resistant bed; but the flatness and smoothness of these level stretches is partly due to the latest action, the leveling action of the shallowing waters. The glacial drift is commonly thin on these plains and patches of bare rock are very frequent, sometimes acres in extent, specially on the Potsdam. A good example is seen at Plessis, which village was formerly called "Flat Rock." On the highways rock frequently occurs in unexpected manner and often forms the wagon track for considerable distance. Although glacial polish and striae occur frequently on the Potsdam the majority of exposures have either lost their smoothness or were never severely rubbed. On the other strata glaciated surfaces are not common.

These plains have been trenched by stream erosion and many of the valley walls are yet steep, those of Chaumont river for example. The differential erosion of the several strata has produced scarps or benches about the margins of the higher plains which are frequently striking features of the landscapes and sometimes are persistent for long distances. These have been described in a former

chapter in connection with the stratigraphy [p. 129]. The valley and scarp topography is certainly older, at least in great part, than the latest glaciation.

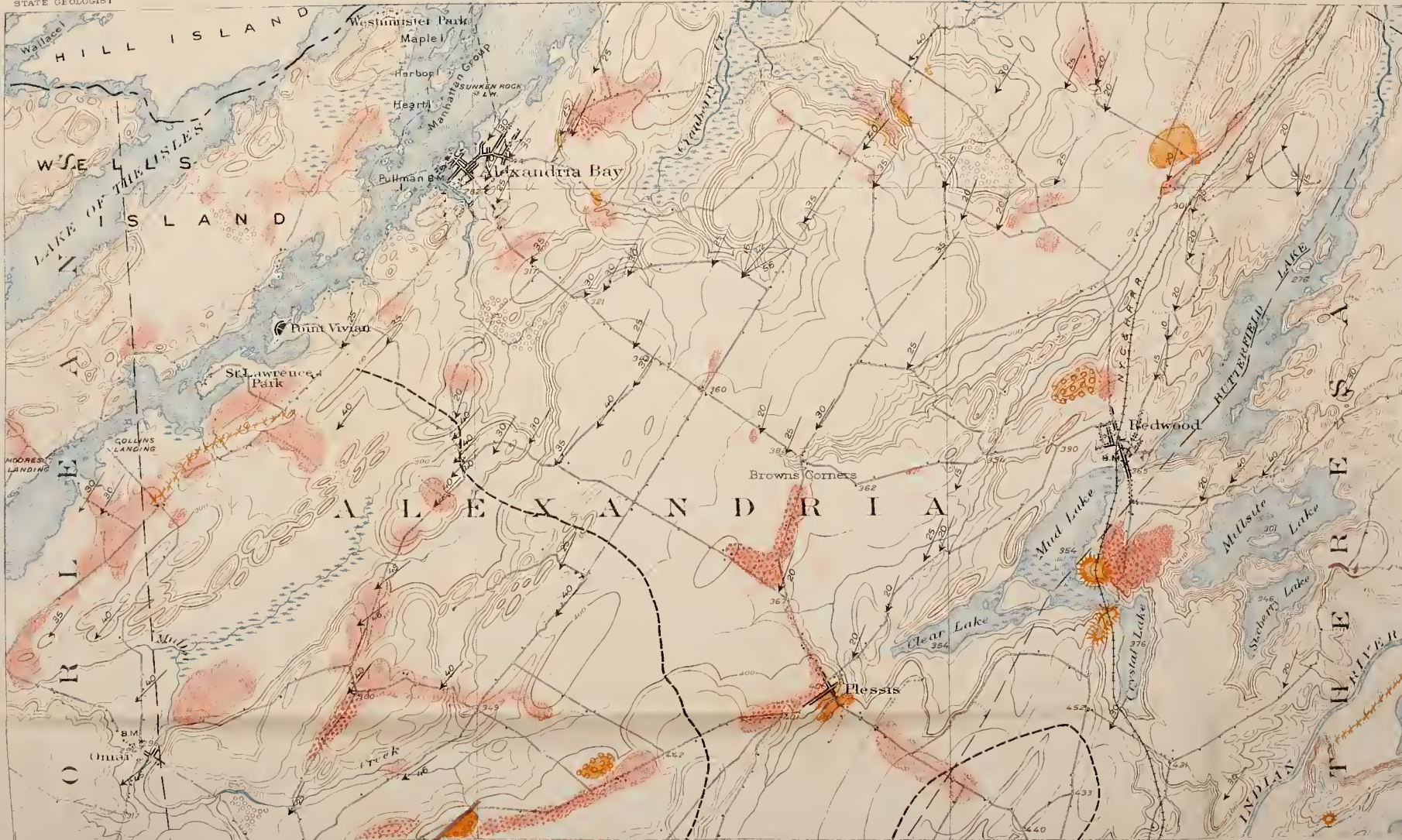
Plains of deposition. Flat stretches of detrital deposits occupy the valleys and basins in the northern part of our area and the lowlands in the southern part. They are broadly developed over the southwestern part of the area, covering nearly all of the Cape Vincent sheet and a large part of the inferior levels of the Clayton sheet. Doubtless the more elevated of these detrital plains have rock floors, those about Lafargeville and Clayton for instance, but the rock is masked; while the valley and basin fillings are deep clay.

These plains are chiefly clay, though sometimes sandy silt and occasionally sand. They represent the distributing and leveling work of standing waters, Lake Iroquois and Gilbert gulf, and are described with reference to origin in a later chapter, page 156. The best example of the sand plains may be seen 3 miles southwest of Theresa, crossed by the Clayton branch of the New York Central Railroad between Theresa Junction and Strough. Beyond this, both east and west of Lafargeville, the plains are clay. From the trains on the Cape Vincent branch of the railroad the clay plains may be seen spread far and wide, as flat as a prairie, all the way from Limerick to Cape Vincent, with a few interruptions of rock or of till ridges.

The more extensive, upland clay plains shade off into till, while some of the valley clays are conspicuously pitted, as if deposited over ice [p. 158, pl. 47].

Lake basins. Perhaps the most puzzling of the physiographic features are the basins or basinlike valleys with steep rock walls. These are more striking in the district of Potsdam and Precambrian rocks of the Alexandria quadrangle, where they hold an interesting group of lakes, the only lakes in our area, excepting Hyde and Perch lakes on the Theresa quadrangle. The five lakes of our area, near Redwood, shown in plate 47, are only the western members of a large group. Some basins without lakes and some steep-walled valleys in limestones on the Theresa and Clayton sheets are probably of similar genesis.

Two facts in connection with these basins are specially to be noted, the steep, scarp-like rock walls and the very small amount of glacial drift. These features seem abnormal in a district that has been subjected to probably repeated glaciation. While these depressions are mostly oriented in general harmony with the physiographic alinement of the region, having a northeast-southwest atti-



LEGEND

Marginal Drift, Moraine

Ordinary moraine

Very stony

Marginal Drift, kame

Sand arcs

Sand knolls

Boulder kames

Glacial Stream Work

Eskers

Gilbert Gulf Features

Bars and spits

Clay Plains

Pitted clay

Glacial Striae

Numerals indicate degrees from meridian

Drainage Divide

Between northeast and southwest flow.

Part of Alexandria Bay sheet

PLEISTOCENE FEATURES: ALEXANDRIA BAY-REDWOOD DISTRICT

H. L. Fairchild, 1909

tude, which very likely was partly controlled by early glaciation, yet a significant number are transverse. Some basins in the vicinity of Alexandria Bay [pl. 47] and others south of Clayton [pl. 46] do not conform to the prevailing direction, and the basins of the Redwood lakes are so irregular in form as to rule out ice erosion as the dominant agent. It seems certain that these basins, like the scarp borders of the plateaus, are due to atmospheric agencies with only small and indeterminate glacial effects; or that they certainly antedate the latest ice invasion. One would naturally suppose that the scraping ice sheet would have rubbed the transverse valleys full of drift. In some valleys and against some scarps the amount of drift is sufficient to be noticeable, but it only masks the foot of the cliffs. In many relatively deep depressions the drift is scarcely perceptible, though some may be buried under the lake silts which occupy the valley bottoms.

Besides the lack of drift filling is to be noted the absence of preglacial talus accumulations. In places the Potsdam is so freely jointed that the cliffs break down under the frost quite rapidly and heavy block taluses occur which are evidently postglacial; but in most cases there is little or no talus, specially outside the Potsdam rocks. In the case of the limestone walls solution might be sufficient agency to remove the products of weathering, and this might also apply to the Precambrian Grenville limestones which form some part of the basins of the Redwood lakes; but such removal can not apply to the almost imperishable Potsdam sandstone. The older fragmental deposits produced by the recession of the cliffs have been removed, most likely by the glacial ice, but without leaving much drift in their place.

The lack of drift in the basins and over the plains clearly implies a lack of drift burden in the latest ice sheet. The cause of this will be discussed later [page 172]. The small abrading power of the ice was probably due to its lack of tools, and evidently it did not have sufficient power of "plucking" or removing blocks in mass to destroy or even seriously cut the steep ledges and scarps which stood across its path.

One suggestion in partial explanation of the somewhat contradictory features, is that stagnant ice occupied the strong depressions over which the upper ice moved by shearing. This would fairly account for the absence of heavy drift in the basins and valleys and the protection of the walls. Another suggestion takes account of the fact that when the latest ice sheet disappeared from this

area the front was faced by about 400 feet of water in the Redwood district. Just what that condition implies in its effects on the ice and the drift is uncertain. We do not know whether the ice melted back as a steep, high front under the dissolving influence of the water, or whether it melted as a thinning sheet, partially protected by its scanty drift, until it was lifted by the water and rafted away.

To epitomize: We conclude that the basins and stronger valleys were excavated by weathering and stream erosion in preglacial or interglacial time, with perhaps some help from early ice erosion; and that the latest ice sheet had little effect beyond clearing out the debris which it found.

Glacial deposits

Introduction. General features. Compared with areas to the southward the area under description has very scanty drift, and has suffered little recent ice erosion. The area did not lie in the zone either of dominant deposition or dominant erosion of the latest ice sheet. Over large portions of the area the rocks are nearly bare, and even in the districts where the drift cover prevails the rock appears frequently and unexpectedly. The amount or depth of drift increases southward but the only heavy moraine lies in the southeast corner of the area [pl. 44].

In considering the character and distribution of the drift it is necessary to emphasize again the fact that during the ice recession the whole area was submerged in the waters of Lake Iroquois, and this was followed by the sea-level waters of Gilbert gulf. The marginal drift was all deposited under subaqueous conditions, and wholly subjected to the distributive action of the shallowing waters.

Over the northern part of the area, where the rock foundation is either Potsdam or Precambrian and the land surface irregular, the scanty drift is largely in the depressions, due specially to the work of the shallow waters. Over the southern districts, where the limestones form wide plains or plateaus, the drift is usually a veneer giving the broad stretches flat or gently rolling surfaces. Because of the lack of drift the preglacial valleys are still open, and one of the characters of the region is the valleys and basins with steep rock walls and silt-plain bottoms. The valleys of French creek and Chaumont river are open down to Ontario level; and the Perch lake valley is filled to only 70 feet over Ontario. The open character of these southern valleys is to be only partly explained by the

stream erosion of the clays which constitute the bulk of the drift. The existence of the Redwood lakes in the northern district is an evidence of lack of drift filling.

The normal and common form of drift in regions of glaciation, the stony clay or clayey mixture of rock rubbish known as "till," is widely found but in relatively small amount. The larger drift masses are of three kinds: sandy or "kame" areas; boulder moraines; and pitted clay plains. The extensive plains of water-laid clay are regarded as glacio-aqueous deposits, and are described in a later chapter.

Till. In the northern portion of the area, where the rocks are Potsdam and crystallines and arenaceous materials prevail, the scanty till is sandy and stony. In the southern district where the strata are wholly limestone these give a clayey texture to the drift sheet.

The superficial till is usually incoherent and yellow or yellowish gray in color. In a few places a compact, hard, blue or blue gray till may be found which is regarded as the product of ice action earlier than the Wisconsin. The most massive exposures of the blue till are found south of our area, at Watertown [p. 166].

No drift masses that could be definitely recognized as drumlin have been noted in our territory, though they do occur over the line on the south, north and south of Watertown. Some molding of the till surfaces suggest drumlinizing of the drift, but apparently the till was too scanty to be rubbed into definite drumlin masses.

Moraines. One heavy moraine lies in the southeast corner of our area, between Black River and Evans Mills, mapped in plate 41. This is the only mass of drift of notable size in the limestone district. In the northern part of the area, where the Potsdam sandstone and the knobby crystallines give irregular surface and rather sharp relief, patches of rough and stony drift that may be regarded as morainal are quite frequent; but the only grouping which merits the name of moraine belt lies about Clayton and eastward north of Lafargeville, shown in plate 46. In general it may be said that the peripheral or morainal drift is not collected in well marked lines but is scattering, patchy and indefinite. In districts where the Potsdam prevails at the surface, with scarps and ledges that supplied very coarse material the ice-piled blocks are liable to be confused with the postglacial debris from frost fracturing of the jointed sandstone. As the Gilbert waters have rinsed away the lighter drift from the higher masses it is not easy to readily dis-

tinguish the ice-heaped blocks from the frost fracture piles; the frost work having, of course, also affected the ice deposits.

In some places the morainal character of the drift is clearly expressed by the well known features of irregular surface, mound and basin topography, but over most of the area the morainal element has been discriminated by one or the other of two features; unusually stony patches or kettles. Very stony fields with heaps of boulders and stone fences, specially if containing considerable percentage of nonlocal rock, have been diagnosed as moraine. Discrimination is needed, for in a district of ledges, scarps or cliffs, specially of the quartzitic Potsdam, the ground may be strewn with rubbish from the native rocks which is not strictly morainal, or peripheral to the ice sheet, even if glacial. This criterion of stoniness is often equivocal and in such cases is usually disregarded.

In districts of clayey till the occurrence of kettles or inclosed basins in the drift is interpreted as indicating ice margin deposits, and sometimes they may correlate with stony tracts. Over limestone floors small sinks may simulate kettles, but over the sandstone and crystallines this deception can not occur.

The above description will suggest how difficult if not quite impossible it would be to accurately map the morainal deposits over the entire area, and this is not attempted. The heavier morainic masses are shown in plates 44-47.

Boulder moraines. Plate 47 shows the larger portion of the Black river moraine, which continues southwest to and beyond Watertown. On this map conventional signs indicate lines and ridges of block moraine. Some of these have high relief and are striking features in the landscape. One photograph is given in plate 56. The character of the ridges as bare limestone blocks is partly the result of wave work of the falling waters of Lake Iroquois. The Black river delta built in the lake was banked against the moraine and partly buried its southeastern border. From the trend of these ridges it is apparent that the ice flow constructing them was from the northwest, and that the ice margin was spreading or deploying on the plain.

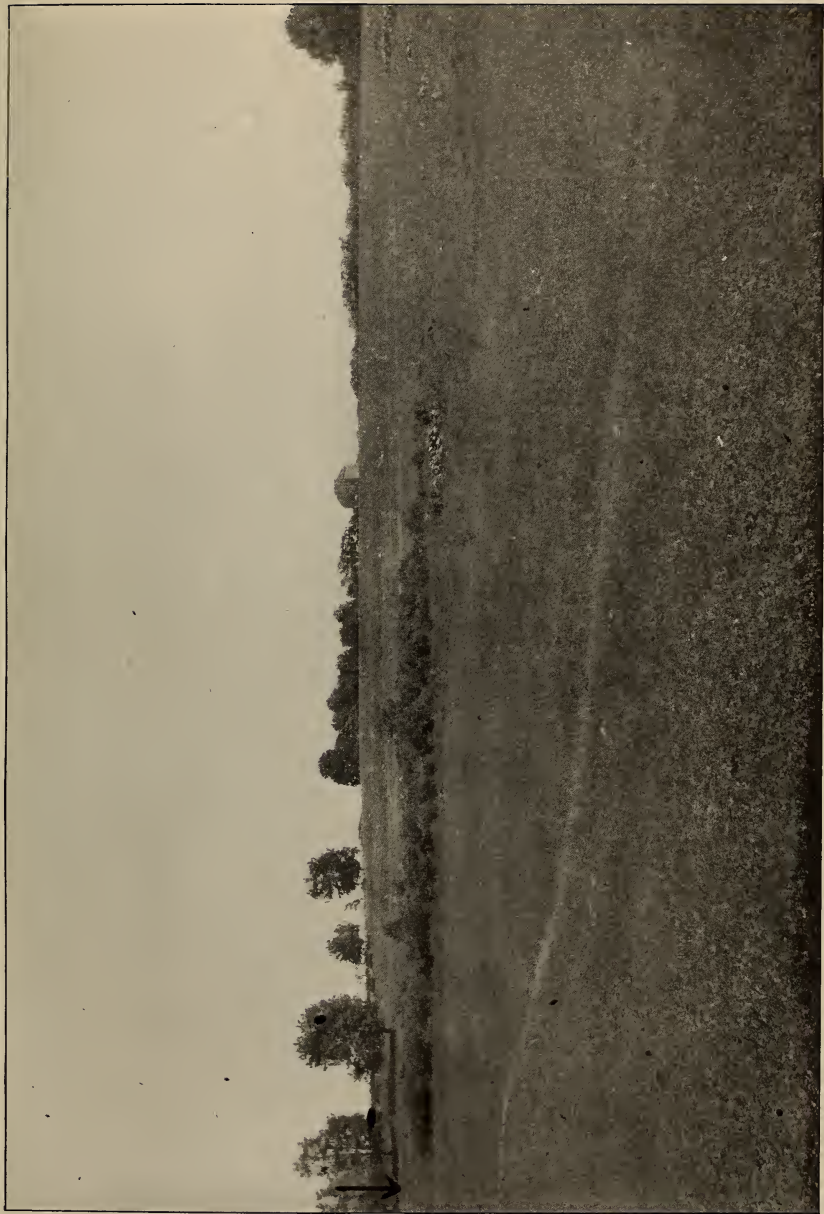
The great massing of limestone blocks with very few crystallines could hardly have been effected by the earlier ice movement from the northeast or north, as the limestone formations do not extend far in that direction. The change in direction of flow enabled the ice to sweep up the rubbish left on the limestone tract on the northwest, and perhaps the new direction of impact, changing from southwestward to southeastward, gave the ice a more effective grip for



Gilbert Gulf bar south of Pine Grove hill, 4 miles northeast of Lafargeville. Looking north. Altitude about 420 feet. Arrow shows position of camera in plate 49. H. L. Fairchild, photo, 1908



Gilbert Gulf beach, Pine Grove hill, 4 miles northeast of Lafargeville. View facing southeast. Altitude of wave work about 440 feet. Arrow shows position of camera in plate 48. H. L. Fairchild, photo, 1908



Gilbert Gulf shore, north side of Haller hill, 2 miles north (by east) of Lafargeville. Looking east of south from the sixth bar from the summit. Bar basin in foreground. Arrow shows position of camera in plate 51. H. L. Fairchild, photo, 1908

plucking on the limestone ledges; which previously had been attacked from the northward.

The massing or localization of the drift, so unlike anything elsewhere in the southern half of our area, suggests that it was the accumulation produced by a readvance of the ice margin, and was followed by a retreat of the ice front to the latitude of Clayton, where the glaciers made another stand, or readvance, with accumulation of another belt of heavy boulder moraine (or boulder kame) in the Clayton-Lafargeville-Redwood moraine.

Boulder kames. The glacial deposits with sharpest relief and, outside the Black river moraine, the most conspicuous masses are the detached or isolated hills of boulders and cobbles which fall in this class. With little attempt to classify the drift forms these would be called bouldery moraine, but on account of the predominance of water-worn materials in the hills and on their flanks, and their isolation, it is thought best to distinguish them as a form between true moraines and typical kames. They stand out isolated, apart from any line or ridge of moraine, being the most striking hills of their neighborhoods. One known as the "Hogsback" lies $1\frac{1}{2}$ miles northeast of St Lawrence and 4 miles southwest of Clayton and is over 100 feet high. Four smaller but conspicuous conical hills lie in chain, in the line of ice flow, in esker-kame fashion, forming the river front of Prospect Park, west of Clayton. These are shown in plate 46. The same map shows the striking group of cobble hills 2 miles north of Lafargeville, having an east-west distribution and somewhat morainic aspect, which have supplied the materials for the best display of Gilbert bars in the entire area [pl. 49-53]. On the edge of this map and reaching over on the Alexandria sheet [pl. 47] is another prominent hill, called Pine Grove hill, 5 miles northeast of Lafargeville and nearly 4 miles southwest of Plessis. Very heavy cobble bars of Gilbert waters are thrown north and south from this hill, shown in plates 45, 46. A pit for gravel has been dug on the summit of the hill. Yet another hill of this kind is shown on plate 47, $\frac{3}{4}$ mile northwest of Redwood. There is a chain of similar hills all along the north side of Grindstone island.

From the large amount of rounded or water-transported materials in these hills, their isolation and their form and alinement, it appears that they were built, at least in larger part, by torrential streams. And as all the area was buried under deep waters of Lake Iroquois during the ice waning it would appear that the streams must have been surficial to the ice sheet and have poured

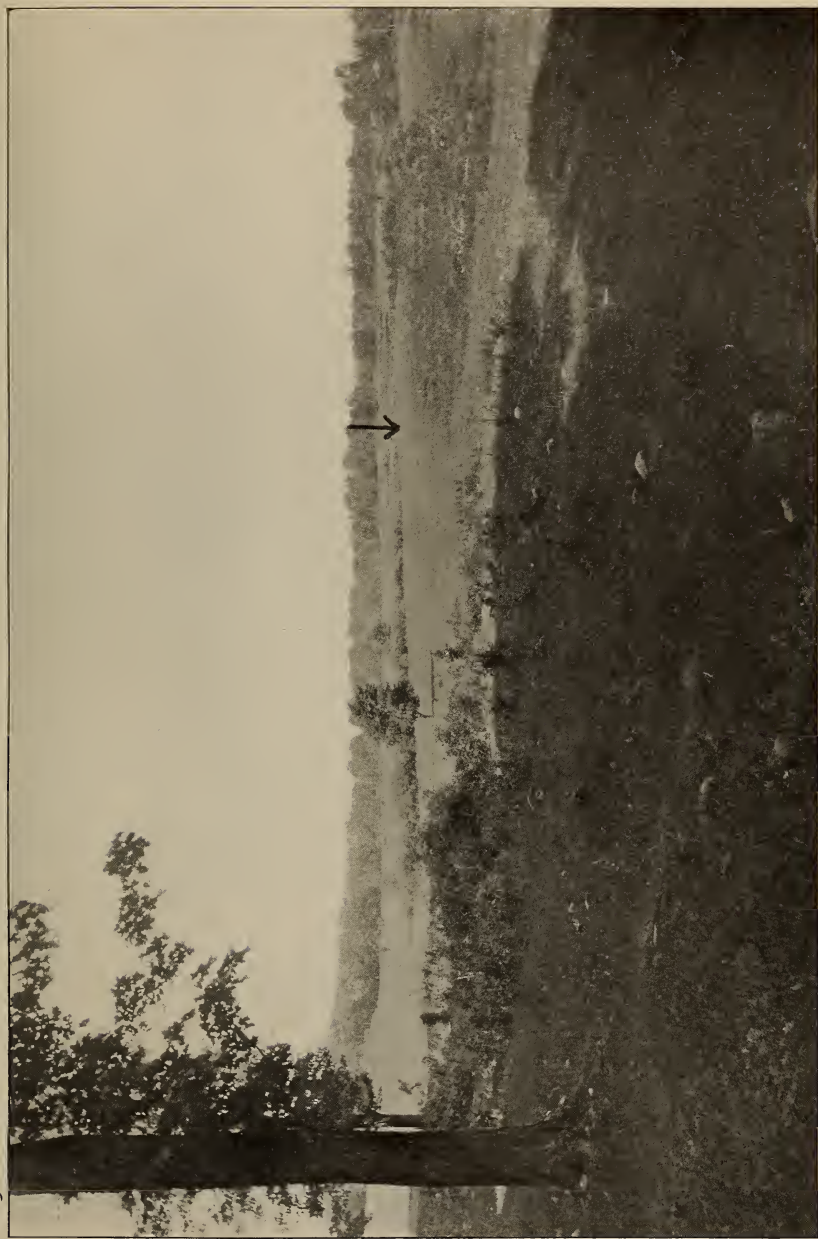
down the steep ice front, into the standing waters. This genetic relationship throws them into the category of water-laid marginal drift, and they are essentially kames. The inclusion of huge angular blocks, apparently contributed directly by the ice, along with the very coarse and largely unassorted materials constituting the bulk of the hills, proves their close contact with the ice front.

The stony composition of these hills has been made more evident by the wave erosion of the waters in which they were buried, the finer materials being swept away from the sloping surfaces. There is a general lack of clayey or adhesive material.

The amassing of such large piles of blocks and boulders, which are only sparsely distributed over adjacent ground, is an interesting illustration of the peculiar mechanical operations of the waning ice sheet, which invites speculation as to the precise genetic processes. The boulder kames hold a considerable percentage of far-traveled fragments, Potsdam and crystallines, which argues against a basal position in the ice of the rock materials, in which case they would be mostly of local derivation. The streams which carried the boulders must have had high gradient, which argues for superglacial flow. This and the unassorted structure of the conical piles argues for a steep frontal slope of the ice at these points. The glacial rivers, like land streams, doubtless had their tributaries, and valleys in the ice, down the walls of which the stones rolled to the streams; so that a river would gather up the rock rubbish from a large area of the ice sheet, and eventually concentrate it in a detrital cone in a notch at the ice margin.

Kames. Deposits of sand and gravel contributed by glacial drainage are well displayed in a number of localities, and several kame areas retain their relief as hills and knolls despite the erosional and leveling action of the standing waters. Indefinite patches of sand are rather frequent and would be much more numerous on our maps if the wide stretches of country between the highways were all examined.

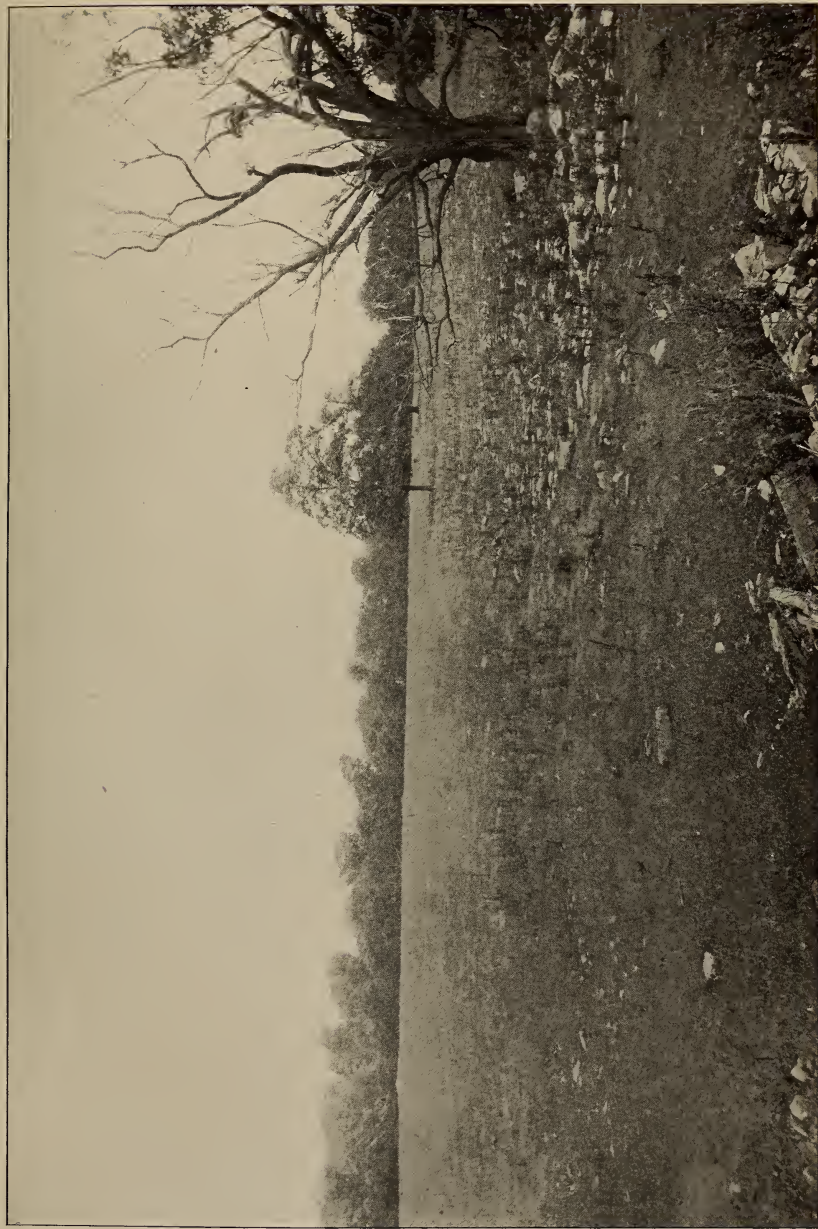
The southernmost and earliest of the kames of the area are in the Black river district, shown on plate 44. Two patches lie south of Felts Mills, close to the limestone scarp. Small patches are west of Black River, and large surfaces north of Sanford Corners and a mile southeast. The sand plain on West creek, south of Evans Mills, marked on the map as correlating with Gilbert waters, may be partly or chiefly kame instead of delta. A kame area of decided relief and glacial character lies 2 miles southwest of Evans Mills.



Gilbert Gulf shore, north side of Haller hill. Looking west from position indicated by arrow in plate 50. Three lower bars and two bar basins in the view. H. L. Fairchild, photo, 1908



Gilbert Gulf shore, east side of Haller hill. Looking southwest from 420 foot bench. Wave work on bouldery drift. H. L. Fairchild, photo, 1908



Gilbert Gulf shore, 3 miles west of Lafargeville. Looking northwest. Showing limit of wave work and removal of drift from the limestone. H. L. Fairchild, photo, 1908

Northward toward Theresa are several extensive sand tracts which are not covered by our maps. East of Strough is a level sand area of 2 or 3 square miles, traversed by the Clayton branch of the New York Central Railroad, which seems to have been mostly leveled by Gilbert waters, but which retains some kame topography along the railroad. Another tract is at Theresa Junction and eastward on both sides of Indian river, and up the river on the west side. Other areas occur: one 2 miles south of Strough, and one a mile south of Theresa. Other tracts, or extension of those noted above, may occur out of sight from the roads.

On plate 46 a series of sand areas are shown extending from St Lawrence northeast toward Clayton, which are related to the Prospect Park boulder kames. Other small sand tracts are marked on this map, and also on plate 47.

Some of these sand areas have not only been modified by the submerging waters but have been worked on by the winds. The dune characters in some cases rather obscures the glacial origin. Some tracts are fine, clean sand, with basins or swampy intervals, like the Theresa Junction area. It would appear that these sands were laid in glacial waters over or among stagnant ice blocks; subsequently modified by the lowering waters; and lastly acted on by the winds.

Eskers. Plates 46 and 47 exhibit several series of kame knolls lying in definite chains in the same direction as the ice movement, some of them blending into true eskers. One stands on the flood plain of Indian river; another close to the St Lawrence river, 4 miles southwest of Alexandria Bay; and two parallel chains 3 miles northwest of Lafargeville. The mapping somewhat overemphasizes the directness and regularity of these esker-kames. The line of sand between the Hogsback and Prospect Park, southwest of Clayton, should probably be regarded as eskerlike, while the four Prospect Park boulder kames, and the Hogsback also, are parts of the chain; that is, they are all deposits made under variable conditions by a single glacial river.

True eskers, gravel ridges of fair continuity and uniformity and lying in line with the ice flow direction, are regarded as deposits in the beds of full loaded glacial streams, either subglacial or superglacial. The true kames are the short lived deltas of the streams, at their debouchment. Only the streams or their deposits which lie in the line of the ice movement could survive. As the ice front recedes the kames may bury or mask the less massive upstream or esker ridges.

Considering their relation to the ice sheet, the kames are essentially morainal in so far as they are peripheral or marginal to the ice sheet. Eskers, specially if of great length, are longitudinal, or parallel to the ice movement, and correspond to drumlins of the ice-laid drift. The esker-kames noted above are not quite typical of either class, and are therefore all the more instructive. In the field these four or five chains are distinct and clean-cut features.

It should be borne in mind that all these detrital deposits were formed when the ice front was bathed by several hundred feet of water of Lake Iroquois. The streams which drained the ice sheet may have flowed in tunnels beneath the ice (subglacial), or in trenches on the ice (superglacial), or rarely within the ice (englacial). To enter the standing water with sufficient force to carry detritus the subglacial streams must have been under considerable head or hydraulic pressure.

The various differences in these water deposits must be sought in the variation of the glacial drainage in its complex relation to the inclosing ice and to the receiving waters, and to the amount and kind of rock debris at different depths in the ice and within reach of the streams.¹

Glacio-aqueous deposits

Clay plains. The largest in volume and the most extensive of the deposits due to glacial agency, direct or indirect, are the clay plains which were spread by the Iroquois and Gilbert waters. Except where in the Black river district the moraine and delta occupy the ground the prevailing drift of practically all the territory south of the parallel of Lafargeville is this clay; and also large areas of the lower ground north of this line. With exception of some till and thinly till-masked rock ridges all the lower ground of the Cape Vincent sheet and the southwest half of the Clayton sheet is clay. East of Clayton and east and west of Lafargeville the plains are clay, blending into till, or eastward at Strough into sand. Excellent views are afforded of these prairielike plains from the railroads to Clayton and Cape Vincent. In the northern district the clay occupies only the valleys and hollows, where the

¹ The reader who wishes to pursue the study of water-laid drift will find a philosophic discussion by R. D. Salisbury in *Glacial Geology of New Jersey*. Final Rep't, 5:113-45.

Kames of Central New York are briefly described by the present writer. *Jour. Geol.* 4:199-59. See also *Am. Geol.* 22:177-80; *Am. Ass'n Adv. Sci. Proc.* 47:278-81.

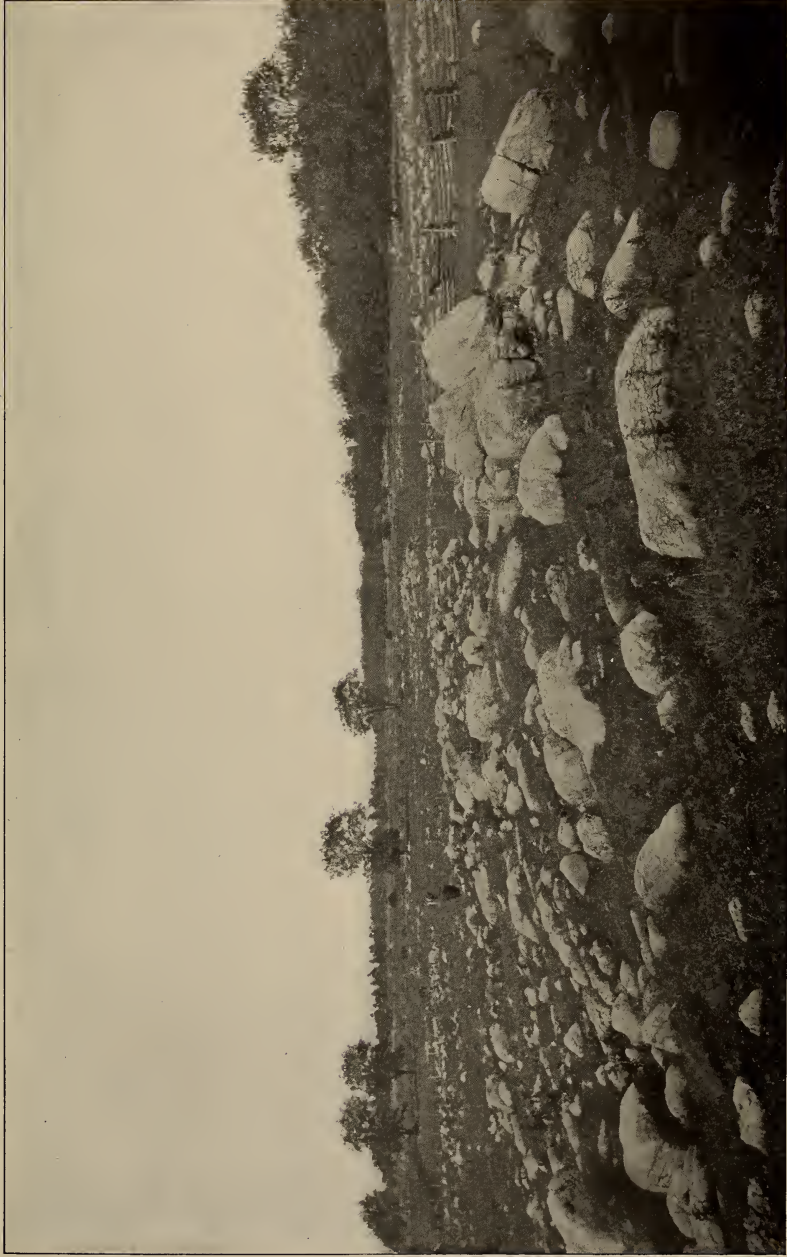
On eskers, favoring their superglacial position, see an article by W. O. Crosby, *Am. Geol.* 30:1-39.



Head of rock-walled basin of Sixberry lake, $2\frac{1}{2}$ miles southeast of Redwood. Looking south. H. L. Fairchild, photo, 1908



Lake silts capping hard, blue till. West edge of Watertown, north side of Black river. Cutting for R. W. & O. R. R., Cape Vincent branch. Looking northeast. H. L. Fairchild, photo, 1908



Boulder moraine, $1\frac{1}{2}$ miles west of Black River. Looking northeast, lengthwise of the ridges. Blocks are limestone. H. L. Fairchild, photo, 1908

smooth clay fillings, as meadows or swamps between the rock bluffs or among the rock knobs, make striking contrast [pl. 29].

The clay is evidently the rock flour of the glacial mill, sifted by the standing waters. Its glacial relationship is shown by the fact that in some localities it shades into ordinary clayey till; by its inclusion of boulders and cobbles, probably ice rafted; and by its composition which is decidedly calcareous.

In many exposures the clay rests directly on glaciated rock [pl. 57] with no mass or visible layer of till or stones intervening. In the gullies or storm-wash hollows a few cobbles or boulders are commonly found, derived from the mass of the deposit, but they do not seem perceptibly more common at the base. The bed of the creek where plate 57 was taken was filled with cobbles from the clay ravine. At the top of this section the lamination was destroyed, but the crushing appears to be very localized, and has rarely been noted elsewhere. However, the structure does not often appear, as the exposed clay quickly loses its lamination and forms a rough, crackled skin over the slope, as shown in plate 58. It is only where the clays are freshly exposed that the lamination becomes evident.

In plate 58 the numerous white fragments scattered over the slope are calcareous concretions, discoid or irregular in form. Evidently they represent concentration of the lime that was originally disseminated in the deposit, but the clay still retains enough of the carbonate to effervesce very freely in weak acid. The latter is true of all the clays tested, except in some cases the topping layers, 1 or 2 feet thickness. The lack of carbonate at the surface may be due to postglacial leaching, and perhaps to original lack of carbonate since the latest beds may have been deposited from well washed material, the ice being far removed to the northward.

Some sections do not contain the lime concretions. This is the case with a great exposure $1\frac{1}{2}$ miles east of Clayton where the river has undercut the bank, giving a section 15 to 18 feet high. The lower part is beautifully laminated, the upper part with older exposure showing the characteristic mottled or crackled skin and some small lime particles. The east end of the clay section exhibits some crumpling of the beds. All these clays effervesce freely.

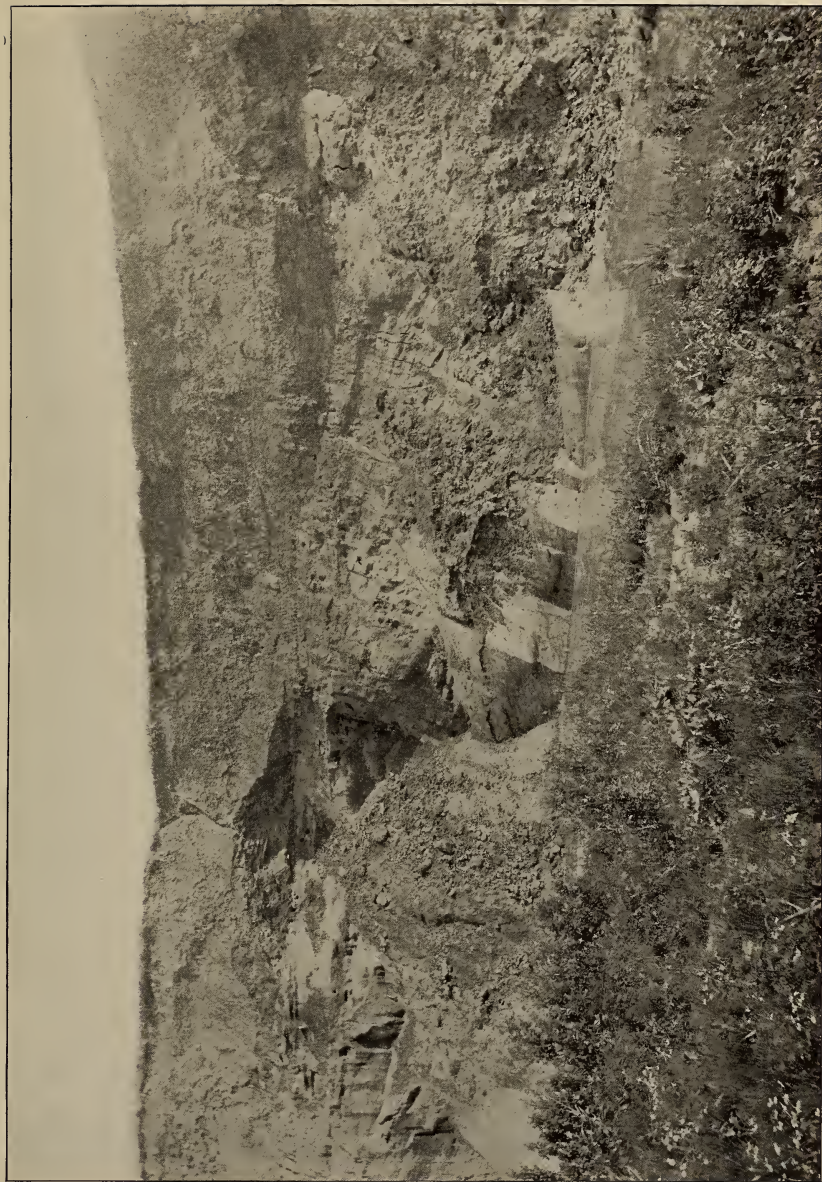
The volume of this clay over the area increases southward, over the limestones, but the total seems excessive in proportion to the scanty drift of other materials. It is possible that the genesis and history of the clay is more complex than would at first appear. Apparently it is all Postwisconsin, for if it were partly the deposit of ice of earlier invasion we should expect to find the deeper and

older beds of somewhat different quality, more or less crushed by overriding of the ice; and tills interbedded between the older and the newer clays. No such features have been seen. In the few sections observed reaching to rock the clay reposes directly on the smoothed rock, and the deposit is similar and homogeneous from bottom upward, and very finely laminated. The cases of crumpling which have been noted are probably explicable by the grounding of icebergs, or perhaps by the thrust of the accumulating weight of clay on weaker borders of the deposit.

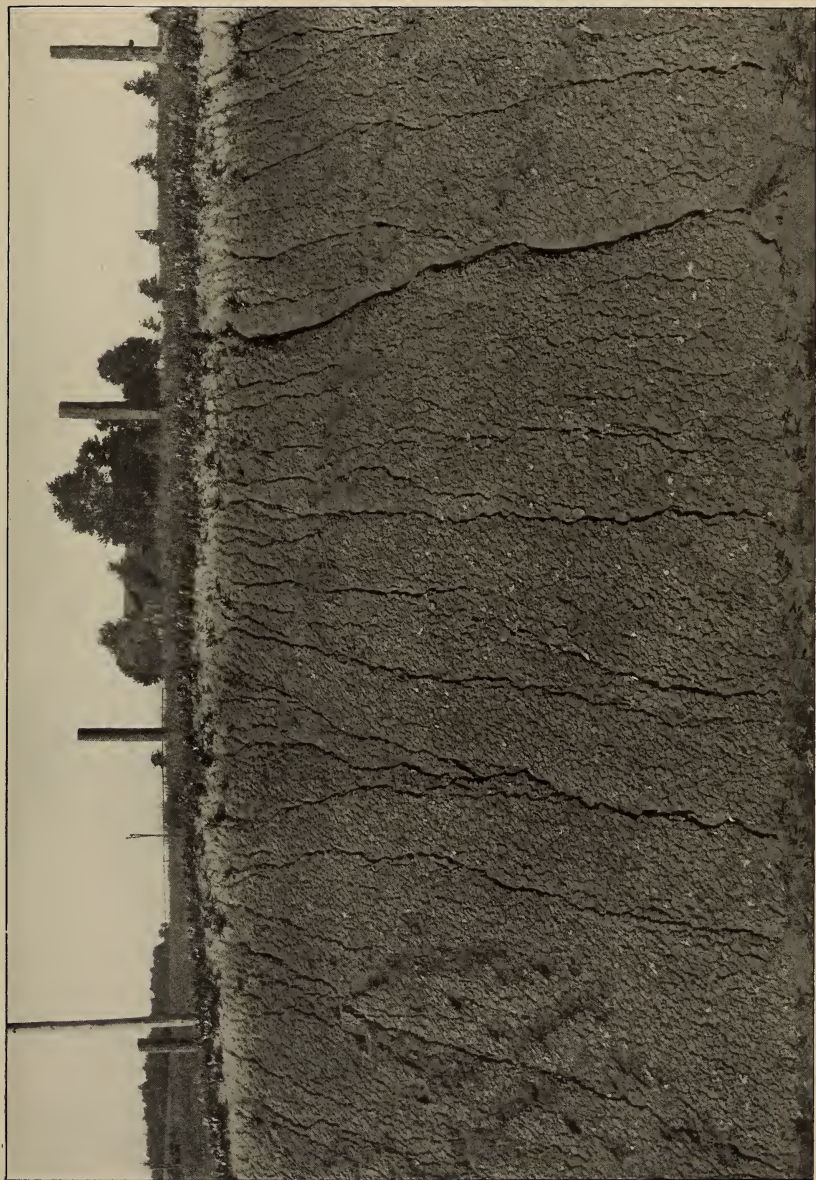
An explanation of the large volume and extent of the clay seems to lie in the consideration of the lake conditions at the front of the waning ice sheet and the mechanical factors working there. In ordinary glacial drift or till the coarse materials remain in mixture with the clay (rock flour) matrix. But the agitated deep water in which all the deposits of our area have been laid down have screened out the coarse from the fine, dropping the coarse near the ice front, and have carried the fine material away by itself farther from the ice front into the more quiet water. It should be understood that the deposits as a whole were accumulated from south to north, following the departing ice front. In other words they grew backward. It is possible that either by lifting or by toppling the breaking ice kept the water agitated and so facilitated its sifting action. The materials contributed by the glacial streams were already under assorting action. Lack of strong, continuous currents, as rivers, or as in tidal seas, prevented the far removal of the silt, and the muddy waters dropped their clay burden over the bottom not far in advance of the ice front. Subsequently the lowering waters scraped the silt which had been dropped on the higher surfaces down into the lower grounds and hollows. As there was no break in the existence of the standing and lowering waters, and consequently no pause in the depositional process, so we find continuity and uniformity in the deposits.

Pitted clays. In the hollows or basins of the Alexandria Bay district [pl. 47] are found deposits of clay which are pitted with basins or kettles. In some instances the silt forms merely mounds and ridges with intervening swales and swamps, a good example being seen 3 miles north of Redwood.

These pitted clay fillings blend on the one hand into till, and on the other into the smooth or merely eroded clay plains. The explanation of their origin seems to be the deposition of the silts over grounded ice or anchored ice blocks. Apparently the ice masses were not melted until the silt deposition was ended.



Silts on glaciated rock, 2 miles southeast of Clayton, by railroad bridge. The rock is Potsdam sandstone; the lower part of the section is sand. The fragments resembling stones are clay masses from the upper beds. Compare plate 58. H. L. Fairchild, photo, 1908



Glacio-lacustrine clay, Dexter. This is the prevailing low-level deposit. An adhering film of the weathered clay hides the lamination. The white particles are lime concretions. Compare plate 57. H. L. Fairchild, photo, 1908

The pitted clays are a link between the ice marginal deposits and the open lake deposits. They might be classed with the morainal or peripheral drift, since they were associated with remnants of the ice front, but the aqueous origin is here regarded as the more important element.

Glacial erosion

General character. The abrasional work of the glacier in this area is more conspicuous in the northern district where the hard Precambrian and Potsdam rocks are in high relief and the drift is mostly in the hollows. Over the southern district where horizontal limestones form the floor the ice erosion was probably greater than farther north, but the evidences are more concealed. The origin of the plains, plateaus and mesas, by preglacial weathering, glacial planing and stream trenching, has been discussed in a former chapter [p. 146].

The more vigorous erosion on the limestones is shown by flutings or ribbing, the lighter and later, by striation and polish. The Potsdam and crystalline knobs seem to have been little more than "sandpapered" by the latest glaciation. The broader surfaces of the more horizontal Potsdam shows effective abrasion in spots only. The impression made on the observer is that glaciation of an earlier ice invasion was vigorous but that the latest ice sheet was comparatively ineffective.¹

Striations. *Occurrence.* The limestones exhibit few striae, as will be inferred from the lack of arrows on the maps of the limestone districts [pl. 44-47]. It is uncertain whether this should be chiefly attributed to the failure of the latest ice to generally abrade the rock surface, due possibly to clayey character of the subglacial drift in this district, or to the obliterative effect of solution and weathering. The limestones are readily attacked by atmospheric waters, as proven by the very numerous areas of solution structures and open joints [p. 133, pl. 26-27, 35]. But in many places the fresh removal of clay or clayey till that would seem to be sufficient protection to the rock reveals unglaciated surface, though usually firm and even, as if a glaciated surface had lost its smoothness. This feature is emphasized by the finding in the same locality surfaces

¹Unfortunately we have no standard or measure of the intensity of ice abrasion or erosion, or glaciation in general. When a writer says that the drift is scanty or abundant, that erosion has been great or small, he expresses merely his own conception of relative intensity, based on his observational experience. It is apparent that different observers might have different opinions, according to the range of their work and their mental attitude. Moreover, the view of the same student might vary with increasing experience and changing emphasis on the various elements or factors.

recently exposed with perfectly preserved polish. While it is possible that this difference in surface characters may be the effect of differences in present conditions of drainage and solution, though improbable, it seems more likely that we have here another illustration of multiple ice work.

In the Potsdam areas the impression is given of general ice abrasion by the frequent patches of polish and striae; but the un-scored surfaces far outnumber the striated. Here, again, we have the uncertainty as to the degree of weathering and destruction of the latest glacial records, because exposed surfaces, apparently of identical quality of rock and equality in exposure exhibit partly highly polished and partly unscratched surfaces. The fact of a general grinding and smoothing of the rock is clear, but quite certainly not by the latest ice sheet.

Direction [see pl. 44-47]. Near the St Lawrence the average direction of striae is about parallel with the river. Leaving out the extreme and aberrant marks they may be generalized as follows: at Chippewa Bay, s. 25° w.; Alexandria Bay, s. $25-40^{\circ}$ w.; Clayton, s. $40-50^{\circ}$ w.; eastward from the river and from the axis of the valley the striae are more variable and swing more southerly. About Redwood some striae are s. 40° w., probably representing the stronger flow of the deeper ice, but a great number range within s. $10-20^{\circ}$ w. About Theresa the greater number lie within s. 10° w. and s. 10° e. East of Chaumont the striae are s. 35° e.; at Evans Mills, $10-20^{\circ}$ east of south and at Sanfords Corners, 30° east of south. The Leraysville moraine [pl. 44] clearly shows the southeasterly push of the latest ice in the district. This easterly swing of the ice in the eastern part of our area was due to the well known spreading or radial flow of a lobation in the ice front. As the ice sheet waned the last portion resting over the area was a broad lobe occupying the St Lawrence depression and having spreading flow toward the east side of the valley. Along the east side of our maps the most westward striae represent the general direction of the maximum flow while the eastward striae are later scratches by the ice margin.

Curved scorings. A remarkable example of curved scorings may be seen on a broad, flat, smoothed surface of Potsdam sandstone $2\frac{1}{2}$ miles east-southeast of Alexandria Bay, about $\frac{1}{2}$ mile west of three corners. The bare area lies in the track and on the north side of an abandoned highway, on land of John Bogert. The locality is indicated by three converging arrows on plate 47, and one photograph is given in plate 59.



Curved glacial scorings on planed Potsdam sandstone, $2\frac{1}{2}$ miles east-southeast of Alexandria Bay. Looking downstream, south 56° west. The scorings curve to south 44° west. H. L. Fairchild, photo, 1908

A considerable area of planished rock is covered by striae which have various directions, from s. 56° w. to s. 16° w. Apparently the markings with the more westerly trend are the older and prevailing ones over most of the surface, the later and more southerly abrasion having softened the older grooves and given a cross polish. But the later motion is also represented by a few strong chatter bands which quite obliterate the older scorings where the latter are crossed.

The curved markings lie in a belt about 10 feet wide and over 50 feet in length now exposed. The scorings are strong, clean-cut, and perfectly parallel. At the north end they lie for several yards perfectly straight, with direction 56° west of south, then they gently curve, southing with steady uniform curvature until the direction is s. 42° w. The curving is still continued where the belt of scorings passes under the turf on the south side of the wagon track. The strong furrows may not be confidently traced throughout the entire length of the curve in distinct individuality, as later abrasion has somewhat obscured them in places, but they are practically continuous and retain their relation and character. The belt of curved scorings is exceptional to the general striae of the broad surface and surrounding bare patches, the prevailing direction being s. $30-35^{\circ}$ w.

The curving lines have no angularity and show no hesitation nor pauses or spasms in the ice motion. In one place a few of the strong scorings in a narrow strip exhibit a perceptible variation from the true curvature, or a tendency to straightness, but taking the belt as a whole the curvature and the parallelism of the lines appear to the eye to be true. The radius of the curve is about 60 or 70 feet. The chord of the exposed belt, including about 15 feet of the straight beginning of the scorings, is 54 feet; and the ordinate is 23 inches.

This glaciated surface is the northern side of a broad rock plain, with no apparent cause in the surrounding topography for the deflection in the ice flow. A narrow valley lies near on the north, across which is a somewhat higher plain. The map, plate 44, shows the general topography.

A significant fact is that the curving belt of scorings, even at the southern deflected end, so far as uncovered, is much more westerly in trend than the prevailing ice movement, not only in the immediate locality but in the great area.

Chatter marks and gouges. The innumerable exposures of the Potsdam sandstone, often of large extent, coupled with the very hard and brittle texture of the rock, furnish many excellent ex-

amples of the effect of the dragging pressure and the percussive force of the boulder-shod ice. The rock is too hard to accept much furrowing or mass removal on the flat surfaces, but its brittleness favors the production of fractures due to compression and to striking force. Of these features two classes will be briefly described.

The hard boulders held as planes and hammers in the bottom ice have produced two kinds of curving fractures, one class convex upstream or toward the boulder, the other convex downstream or concave toward the boulder. Those with the concavity facing downstream, that is to say, with the convexity toward the producing tool, fall under the category of "cones of percussion" or "chatter marks." Many excellent examples of these concentric fractures are seen, some of large size or up to 10 inches of arc and forming from one quarter to one third of the circle. Sometimes the parallel concentric fractures are closely crowded, several within an inch, but are usually somewhat more open, three or four or less to the inch. Figure 13 is traced from a "rub" taken by the road near the house

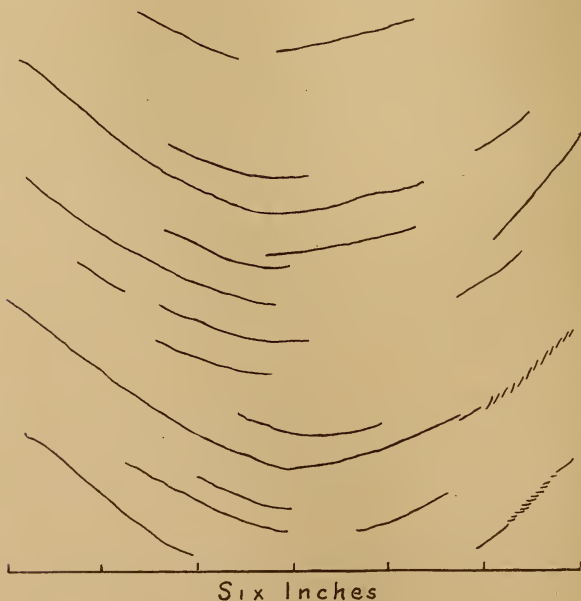


Fig. 13 Chatter fractures

of William Northrup, 3 miles northwest of Redwood and 3 miles east of Alexandria Bay, and about $\frac{3}{4}$ of a mile northeast of the curved scorings described above. In this case 11 fracture lines lie within 4 inches along the axis of the curvature, most of them being

short. The longer lines have an arc of 6 inches or a radius of about $3\frac{1}{2}$ inches.

Another excellent illustration of the chatters is on the highway 3 miles north of Redwood on the road to Chippewa Bay, at the point indicated on plate 47. Several very large examples occur in the middle of the street in Redwood village, just below the Dollinger House. Smaller examples are so very numerous that no notebook record was made of them. Fine examples occur with the curved scorings.

The chatter fractures dip so steeply into the rock that rarely is there any flaking of the surface rock. In many instances no axial grooving or crushing of the rock is visible, the appearance being as if the rock had been abraded and resurfaced and polished so as to leave merely the clean-cut concentric fracture lines. Such abrasion is more than possible but is very slight, as early striae having the direction of the axes of the chatters are not obliterated. Commonly there is some evidence along the axial line of the pressure by the unsteady or chattering tool.

The other class of fractures, having the concavity facing upstream toward the tool, are much less regular or true than the chatter fractures. In both classes the cracks dip downstream or away from the point of the tool, but in these gouge fractures the angle of dip is much less than in the chatters, and commonly there is considerable flaking of the rock or removal of the feather edges of the surface rock. These cracks fall in the class of "concentric gouges" or "disruptive gouges" of earlier writers.¹ The action seems to have been a sort of drag or pull on the surface of the rock by pressure of a boulder with broad area of contact, but without pounding or percussive force. The process was a plucking by dragging pressure.

These gougings are not as common as the chatters, and only two good localities were noted. One of these is $\frac{3}{4}$ mile south of the county line between Jefferson and St Lawrence counties, on the west road to Chippewa Bay. The other occurrence is on the road east of Goose bay and on the south side of Crooked creek valley. The first mentioned is on the south end of a plain, the latter on a surface facing north, where the ice was pushing against an upslope.

The gouge fractures are rarely true circular curves, in which cases they may be mistaken for chatters, but commonly they are irregular

¹A full description and discussion of these singular phenomena connected with glacier mechanics is given in Professor Chamberlin's paper, Rock Scoring of the Great Ice Invasion. U. S. Geol. Sur. An. Rep't 1888. p. 216-40. Reference to other writings is there given.

in both form and relation. They lack concentric parallelism, in other words are not in regular series; and they are not always transverse or normal to the line of motion of the tool, as shown by the band of crushing or gouging. Figure 14 shows these characters.

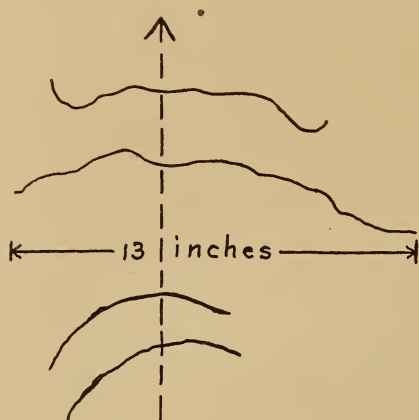


Fig. 14 Gouge fractures

To summarize: the gouge or dragging fractures would seem to be the effect of a steady dragging motion of a boulder with large contact surface, while the chatters are the product of unsteady, percussive or pounding movement of points of boulders or small contact surfaces.

Limestone flutings. Over large districts in the southern part of the limestone area the rock surface is worn into series

of parallel, cylindrical ridges of several feet diameter, separated by equally regular troughs or hollows. These features which can be attributed only to ice erosion are illustrated in plates 60-63. As the amount of erosion and the direction of the ribs and ice movement are inconsistent with the work of the latest ice sheet the discussion of the topic is deferred to the next chapter.

Prewisconsin glaciation

Theoretic considerations. In the preceding pages several features have been mentioned as difficult of explanation or inconsistent with the conception of a single ice invasion. The facts and argument favoring the view of multiple glaciation will be summarized here.

If the generally accepted conclusions of glacialists, that the northeastern states have been repeatedly glaciated since Tertiary time, are well founded, it is quite impossible to except or exclude New York from all ice invasions earlier than the latest, or Wisconsin. The several glacial epochs recognized in the Mississippi valley have been named on page 137. The very old drift of New Jersey and southeastern Pennsylvania is believed to be as old, certainly, as the Kansan, and probably represents the Preadfontian, which is now sometimes called the Jerseyan when referring to the

eastern region. The drift of northwestern Pennsylvania lying in advance of the Wisconsin drift, is believed to be as old at least as the Kansan. For an ice sheet to so expand as to reach either northwest or southeast Pennsylvania without trespassing on New York seems impossible. Hence we are forced to the belief, apart from any evidences on the ground, that the State has been more than once in the climatic condition of Greenland at the present time.

If the State has been overrun by ice sheets more than once it seems rather strange that geologists have not recognized the phenomena and discriminated the records. It must be admitted that we now lack the evidence afforded by multiple till sheets, separated by temperate climate deposits such as are found in the Western States. With attention directed to this subject it is probable that some conclusive proofs will be discovered.

But while no single fact or class of phenomena yet found furnishes conclusive proof of more than one ice epoch, we have a variety of indirect evidences, and many features are well explained only on that supposition, and several lines of study converge toward that conclusion. Moreover, to attribute all the glacial phenomena to a single ice sheet involves inconsistencies, such as the evidence of impotence in erosion of the latest ice, with indication of vigorous erosion formerly; and the lack of glaciation surfaces on ice-shaped rock as well protected as places showing hairline striae and polish.

The glacial features of the Thousand Islands region which are not satisfactorily referred to the latest ice work probably can not be attributed to an ice sheet as ancient as the Kansan, but would seem to be the effect of some recent ice epoch. Whether it was one of the later Prewisconsin invasions or only an early Wisconsin episode we may not now decide.

Anomalous physiography. South of our area, in the central part of the State, many channels of ancient drainage are found which are not Postwisconsin. In the area under discussion these features do not occur because the whole region was drowned in deep water during the ice recession. But the region has its own peculiar topographic features that are difficult of full explanation under the conception of a single ice transgression. The valley, basin and scarp topography has already been briefly discussed [p. 146]. Other points will be touched on below, but a full discussion of the difficult problem requires more fieldwork specially directed to the particular features.

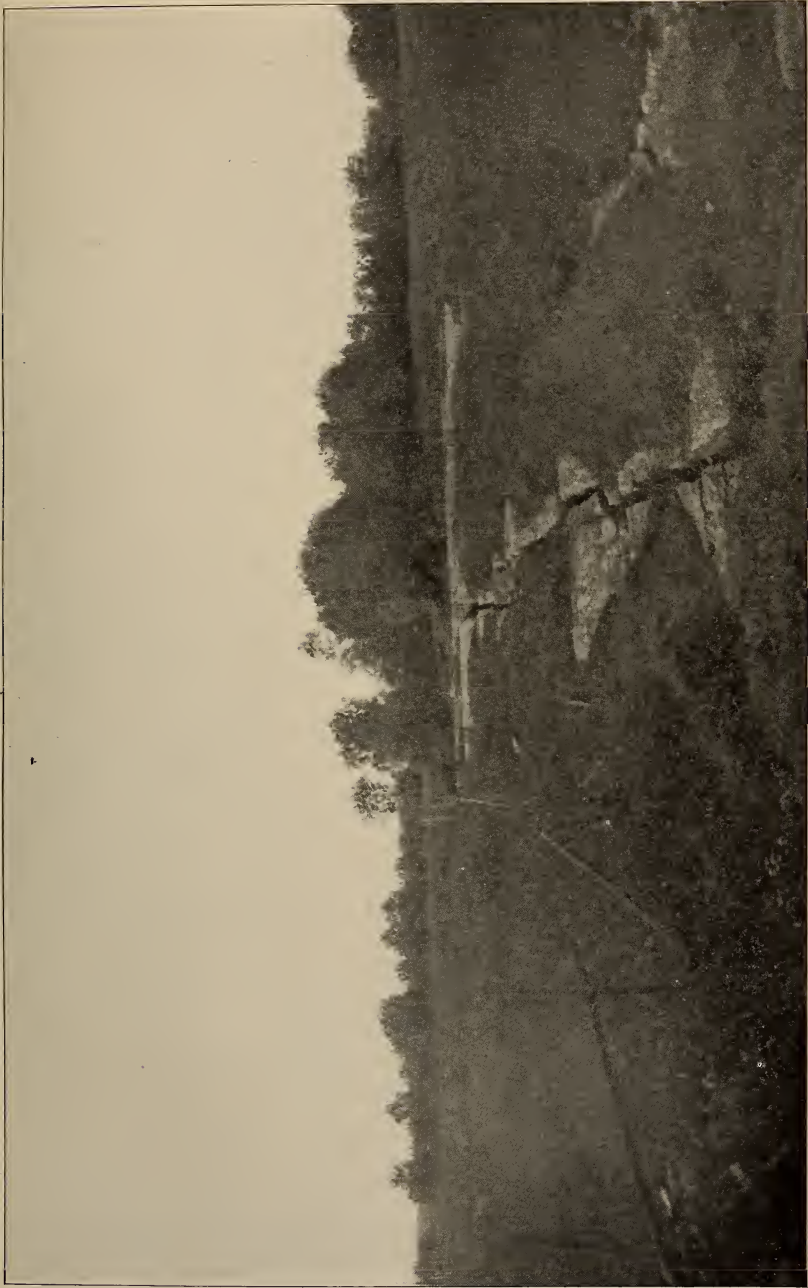
Old till. As far as the writer is informed, the first one to recognize Prewisconsin till in New York was F. B. Taylor. In the summer of 1905 he directed attention to the very compact, resistant, stony, blue till in the bottom of the deep valleys southeast of Buffalo, which he confidently pronounced older than the overlying and prevailing Wisconsin drift. Subsequently the writer noted other occurrences of similar till. In 1907 Frank Carney published an account of what he regarded as old till in the Keuka valley.¹

No soil zones or forest grounds lying between the supposed old till and the superficial till have yet been found, to prove the fact of an interval of deglaciation, though such finds may be expected. The writer has noted very sharp distinctions between the two tills, with incorporation of the lower into the upper. An important locality is along the new cuttings for the shortened tracks of the Delaware and Hudson Railroad west of Schenectady, between Kelly station and Duaneburg. Here an incoherent, yellow till, capped with gravel, directly overlies a very hard, dark blue till. The contrast between the two is very striking and the line of separation is very distinct in some sections; while in places the older blue till has been plowed up and masses have become incorporated in the yellow till. The blue till retains its color and consistency even when exposed for considerable time to the weather, masses which have lain in the field over the winter being only partially disintegrated. The writer was told that the steam shovels were able to cut the blue "hardpan" with much difficulty and very slowly.

The blue till has a very different composition and derivation from the overlying and oxidized yellow till. It is impossible that an ice sheet, producing from its burden of ground-up shale and limestone the hard blue till, should suddenly cease to deposit this and at once lay down a yellow oxidized till of entirely different origin. We have here good proof of at least two distinct episodes in ice work.

The writer has not noted in our Thousands Islands area any example of tills comparable to the old, blue tills farther south, though Cushing thinks that he has seen them. But they probably do occur just south of the boundary, in the northern part of the city of Watertown. Here begins a group of drumlins that extends southward. In the mass of the drumlin forming the dome-shaped hill north of the Black river, and in the small drumlin ridge in the northwest corner of the city, where the Dexter electric line crosses

¹ Pre-Wisconsin Drift in the Finger Lake Region of New York. *Jour. Geol.* 15:571-85.



Postglacial weathering. Open joint across limestone ribs, 1½ miles east of Dexter. Looking northwest. H. L. Fairchild, photo, 1907

the Cape Vincent branch of the New York Central Railroad, a hard, gray blue till appears that is very unlike the prevailing drift of the northward area. The latter exposure is shown in plate 52. The resemblance of this drumlin till to the "old" tills farther south is as close as might be expected when the differences in latitude, source of the material, etc. are considered. However, we must recognize that the drumlin till was subglacial, deposited beneath the ice and under tremendous grinding pressure; while the surficial drift of the area was dropped in standing water, and is consequently incoherent, sandy, inclined to yellow or gray colors, and carry few striated or abraded stones. The production of masses of subglacial drift or drumlins is a sort of work which the later ice did not do north of Watertown, at least to noticeable extent, and it is doubtful if it did such work at Watertown. However, the drumlin till is inconclusive, until we know if the Watertown drumlins are the work of the latest ice or of some earlier invasion. This Watertown till is not in valley bottoms or deeply buried, but in hills above the levels of the plain.

Limestone ribbing. Over the southern part of the Clayton quadrangle the limestones frequently exhibit series of parallel ribs or flutings, a sort of washboard structure on a vast scale [pl. 60-63]. These ribs positively have no genetic relation to the joint structure of the rock. They are pronounced convexities, often quite cylindrical but commonly rather flat, with a breadth from crest to crest, or across the base, from 2 to 10 feet; the usual breadth being 3 to 5 feet. The hollows between the ribs are usually filled with drift or soil, but when cleared they show quite cylindrical troughs of uniform width and fair curvature, and parallelism with the ribs. By solution-weathering the sides of the flutings are rarely steepened and the bottoms perforated by solution holes, as in plate 63.

Within any single exposure these flutings are strikingly parallel [pl. 61] and are approximately so over the whole region, having a direction about s. 45° w. Scores of them have been measured with that direction, over all the area between Dexter and St Lawrence village. The extreme variation in direction is s. 40° w. for the heavy ribbing east of Dexter, and s. 50° w., south of Dexter, shown in plate 63. Two other localities toward St Lawrence gave the latter compass direction.

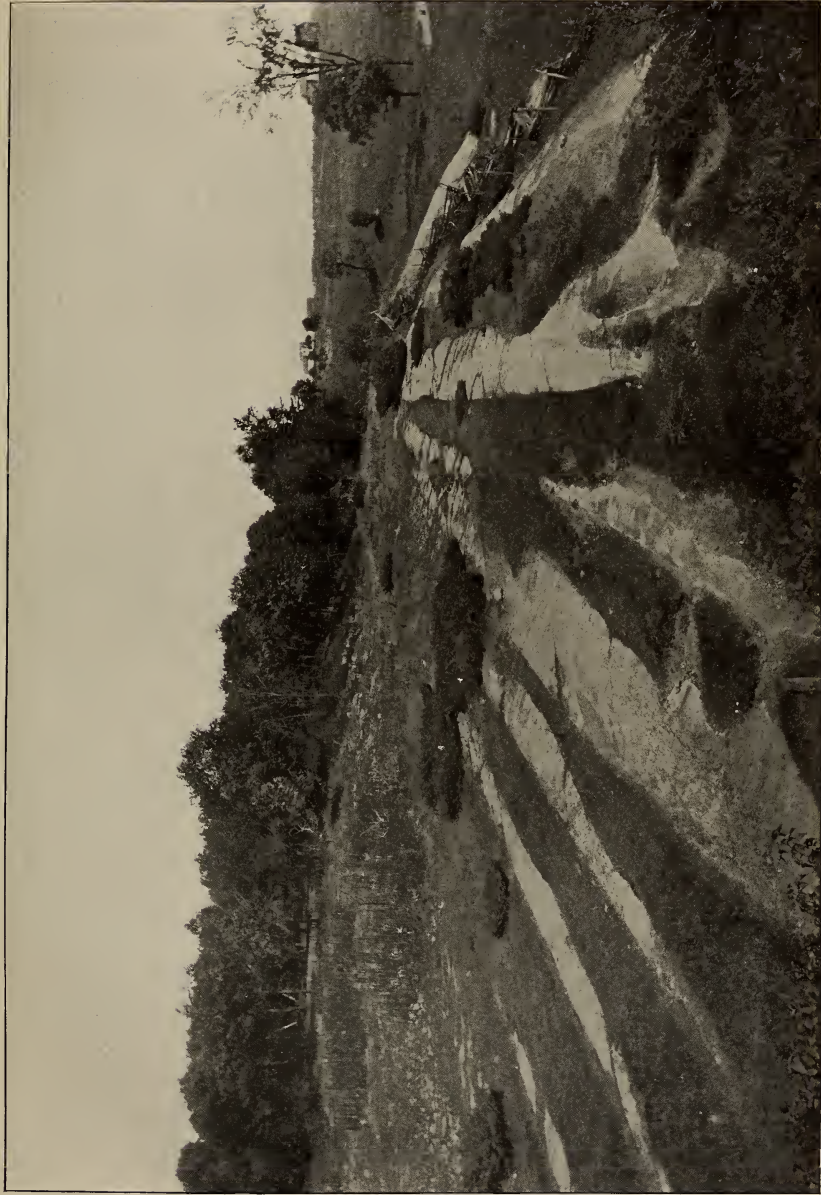
Speaking broadly the flutings have lost all their glacial surfaces, retaining only the erosional form, for their origin by ice erosion of the limestone seems certain. In a very few cases a suggestion of the heavier scorings are preserved, and some minor flutings on the

ribs. The ribs which have been long exposed have been so corroded by weathering that one might question even their glacial origin. But those flutings also which are only recently uncovered have lost their glaciated surface, though they may show the perfect polish of a later glaciation oblique to the ribbing. This fact is important with reference to the age of the ribbing.

In plate 61 we see a typical example of the ribbed limestone, the locality being the west side of a hollow several rods west of the railroad station at Threemile Bay. The ribbing is s. 45° w. The three ribs in the foreground at the lower right corner have been strongly cut and polished by an ice flow having direction s. 55° w. This change of 10 degrees in direction is not unusual for the same ice sheet, and taken alone would be weak evidence of dual glaciation. The important fact here is that the later ice movement has scored and polished the ribs obliquely, striking them on the east faces, and the later polishing is perfectly preserved though apparently has been exposed as long as other portions of the ribs where no glaciation is visible. The ribs are being freshly uncovered by the wash on the slope, but the only glaciation seen is that oblique to their direction. The only reasonable inference is that the ribs have lost the glacial surface by old age weathering and that the oblique polish is from a later ice rubbing. The ribs are rough and corroded where not cut by the more westerly planing, and it is certain that the lack of striae and polish on the ribs can not be due to merely recent weathering.

The ribs and hollows have no fixed relation to the joints of the rock. In the locality of plate 61, while the ribbing is s. 45° w., the joints, so far as they have any dominant trend, are s. $75-85^{\circ}$ w. Nowhere are the joints so true and parallel as the ribbing. Only occasionally do joints appear in the furrows but they commonly lie boldly across the ribs and are frequently opened widely, as in plate 60, where some joints are a foot wide and 10 feet deep. The removal of the clays of the latest deposits from the ribbed surface shown in plate 60 has been chiefly by subterranean drainage through these open joints. It seems very unlikely that these open joints were produced with their present size and form since the last glaciation and beneath several feet of the Dexter clay [pl. 58]. The joints certainly are the product of atmospheric weathering and solution, and it seems a safe inference that they represent a time of long exposure antedating the last ice work.

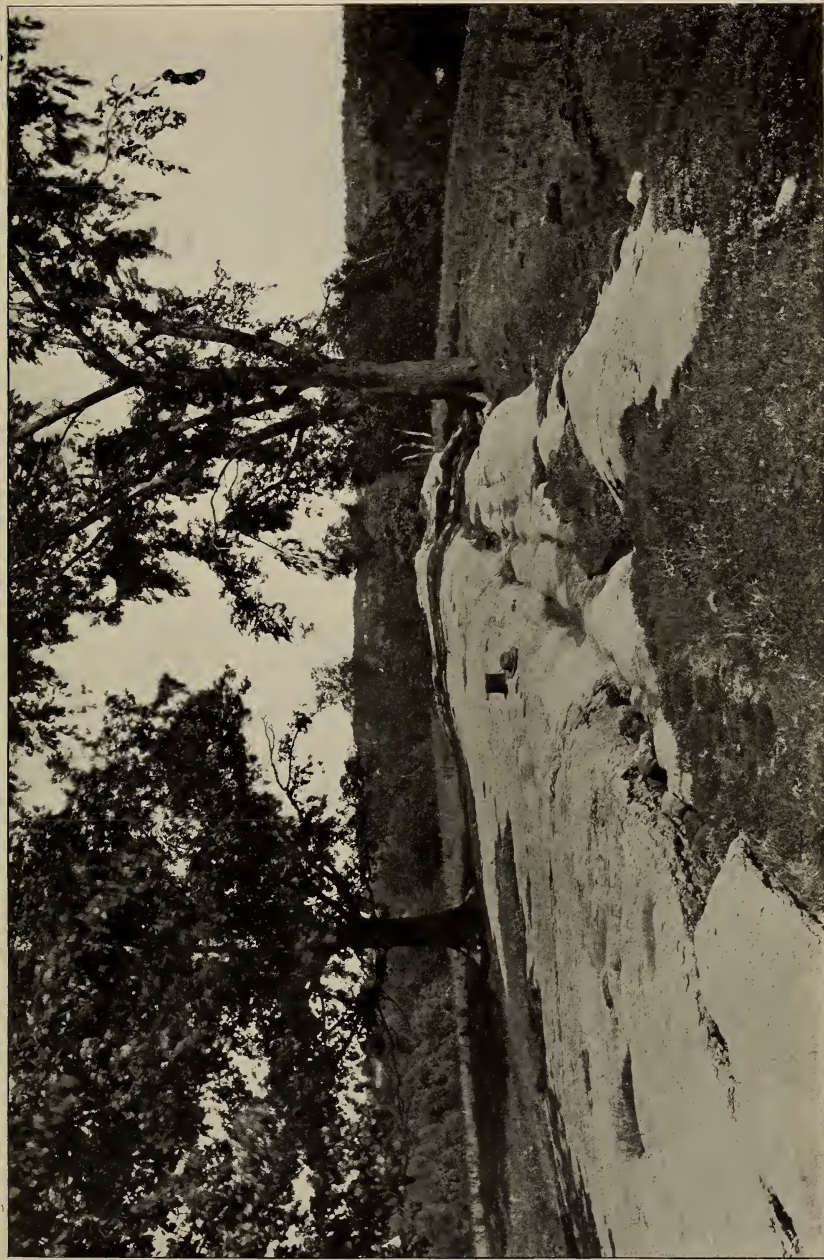
These exposed ribs east of Dexter, visible on the north side of the electric line, lie in a hollow in the clay, as shown in plate 63,



Glacial ribbing in limestone, Threemile Bay station. Looking north 35° east. Compare plates 62 and 63. Direction of ribs s. 40° w. Recent glaciation in lower right corner, s. 55° w. H. L. Fairchild, photo, 1908



Weathered rib of limestone, 1½ miles west of Brownville, south side of Black river. Looking southwest. Compare plates 61 and 63. H. L. Fairchild, photo, 1908



Glacial flutings in limestone, $\frac{1}{2}$ mile southeast of Dexter. Looking n. 50° w. Compare plates 61 and 62. Directions of ribs s. 50° w. H. L. Fairchild, photo, 1908

the hollow being produced partly by the washing of the clay cover down the wide solution joints. On the sides of the hollow the ribs are being newly uncovered by the storm wash and the tramping of cattle, but no trace of glacial polish was seen, the new surfaces being similar to the longer exposed surfaces of the middle of the ribs. Masses of chert standing 2 or 3 inches above the limestone surface prove a long period of solution of the rock surface, which seems impossible beneath the present clays in the short time involved. Enforcing this conclusion is the fact that only a number of rods distant, in the gutters of the electric road under similar clay cover the same limestone shows elegant glaciation. But while the ribbing is s. 40° w. the preserved glacial scorings are variable, ranging from s. 50° w. to s. 10° e.

These two examples of the ribbing, which can be multiplied, will give illustration of the quality of the evidence they offer in favor of at least dual glaciation in recent time. These flutings are widespread, remarkably uniform in direction (generally s. 42-45° w.), symmetrical and true in form. They can not be attributed to weathering, nor jointing, nor wave work, nor water corrosion, all of which have left conspicuous records in the district. Undoubtedly the ribbing is old glacial, and it represents a glacial abrasion vastly more energetic than the similar work of the latest ice sheet.

Weathered surfaces. The considerable weathering which the limestones have suffered is shown in plates 23, 26, 27 and 63. Doubtless some part of this corrosion is postglacial, specially on the more exposed patches and on cliff edges where the rock was not buried by the drift; but it must not be assumed that these etched, corroded and open-jointed surfaces were all left smooth and glaciated by the latest ice sheet, as that is the question under discussion.

The uncovering of corroded surfaces which have been under clay that would seem to have been sufficient protection from the postglacial weathering, as illustrated in plates 61 and 62, argues strongly for nonglaciation of such surfaces. The conditions shown in plate 60 seems to prove that great open joints existed in the limestones previous to the deposition of the glacial clays.

Probably many of the deeply corroded surfaces were recently buried under ice or lake deposits which have been swept off by the wave erosion of the standing waters and the subsequent and now acting storm wash. Without more special study on the ground it is impossible to estimate the amount of postglacial weathering. In some places it seems very small, and where slightly covered prac-

tically nothing. Such cases give the impression of slight corrosion since the ice removal. On the other hand the existence of broad surfaces of exceedingly rough and open-jointed rock, from which the farmers have to fence their cattle, and the location of which would seem to have been favorable to glaciation, give the suggestion of large postglacial weathering. The critical question is, were the latter surfaces glaciated by the latest ice sheet? It would appear that a duration and intensity of postglacial weathering which has not destroyed the glacial polish on the limestone ribs shown in plate 61 could not justly be held responsible for the open joints and rough surfaces shown in plate 60, where a deep clay cover has been removed chiefly by washing down into the open joints and being carried away by subterranean flow.

The amount of recent weathering is conspicuously greater in locations where the surfaces have been subjected to wave wash of the Iroquois and Gilbert waters, this being specially effective in both solution and mechanical removal of the limestone.

Old planation surfaces. If the ribbing on the limestone was in existence before the last ice invasion then, of course, the limestone plains and plateaus were formed previously; and it has already been stated that the broader topographic features are confidently believed to antedate Wisconsin glaciation. An ice sheet with sufficient vigor to do the plucking and planing necessary to give the limestones and Potsdam sandstones their breadth of flatness should leave abundant evidence in glaciated surfaces; and the limestone ribbing is a relic of such effective erosion. Again, the general lack of glacial polish is the fact which requires explanation.

The plains of Potsdam sandstone present the same question. Over broad surfaces of the very firm, hard, insoluble sandstone, either bare or practically unprotected by any impervious cover, only a minor part exhibits striae or polish. Certainly it was once all vigorously glaciated, for in no other way could the level, even, firm surfaces be produced. From hasty examination it is impossible to confidently decide whether the patchy scoring and polishing is due to weak recent glaciation on an old weathered surface, or to retention of polish under present weathering. The former alternative, recent partial smoothing on an old weathered surface, is more in harmony with the general body of fact; and it seems more probable that the recent ice sheet failed to generally polish the old weathered surface than that patches with finest polish and hairline striae should be so perfectly preserved while surrounding surfaces

with apparently identical physical conditions have lost all traces of recent glaciation.

Weak erosion of the Wisconsin ice sheet. It will be seen that the critical point in this study is the erosional impotence of the latest ice sheet. With this established then at least dual glaciation of the region must be accepted.

The principle is recognized by glacialists that intensity of ice erosion depends on pressure, velocity of the bottom ice, and its armament or tools. The glacier can do its most effective work of abrasion when the basal ice is only moderately charged with rock rubbish, and that of hard texture. A heavy burden of subglacial drift serves to diminish the plasticity of the ice and so reduce the velocity of flow; while at the same time it acts as protection or a buffer for the subadjacent rock. For this reason rapid corrasion is a self-checking process.¹ On the other hand it is certain that clear ice can not abrade the bed rock at all. A moderate load of hard tools is the most effective for abrasion.

The first ice sheet that transgressed our region found it deeply covered with the residual product of millions of years of weathering, and could do no effective erosion until not only the sheet of geest (regolith) on our area had been removed but also that lying on the region northward into Labrador and Canada which was swept by the southward ice flow. The theoretical stages would be as follows: (1) the scraping away of the decay product and bearing it far southward, as no very heavy moraines lie near our area; (2) vigorous erosion during the phase of favorable load, with harder tools from the plucking of the fresher rocks; (3) weak abrasion by the clearer ice after the glacier had swept its floor and reduced the asperities in its path.

On the postulate of a single ice invasion of the Thousand Islands region it is necessary to assume that after the ice had removed the abundant product of Prepleistocene weathering it used its medium load of debris to plane the hard Potsdam and to plane and deeply flute the limestone, but at the same time failed to rub down the scores of comparatively abrupt cliffs and scarps which opposed its motion. Here we find another inconsistency. Without further discussion it will be understood that the assumption of a single glacial epoch involves serious contradictions and difficulties in the explanation of the phenomena of the region.

Assuming dual or multiple glacial epochs the features and history are fairly clear. The accumulations of long eras of rock weathering

¹ Geol. Soc. Am. Bul. 16:26.

were swept southward by the earlier glaciation. Later ice work with more abrasive power planed the harder stratified rocks, grooved the limestones, modified the topographic forms by softening the scarps and rock knobs and straightening the drainage lines. One or more long interglacial epochs partially restored the characteristic atmospheric-erosion forms of the Theresa and Pamelia scarps and cuesta fronts; reexcavated the valleys and basins; and destroyed the surficial glaciation on the sandstones and limestones. The latest ice sheet finding the northward region denuded of rock debris and smoothed by the earlier glaciation was unable to arm itself for effective erosion and thus handicapped was competent only to weakly abrade in places. It is possible that while the deglaciation interval in our district produced some weathering effects the northward (Labrador) region was continuously snow-covered and the ice was not able to pluck a new supply of granitic tools.

Undoubtedly there were important differences in the behavior and mechanical effects of the several ice sheets, due to differences in rate of accumulation and velocity of flow; of depth and pressure; of temperature and rate of waning; and these combined with, and an effect of, climatic variations.

It would have been entirely proper in this writing to have assumed multiple glaciation and confidently to have explained the singular features of the area on that basis. Perhaps the method of argumentation which has been used is somewhat confusing to the reader, but he will better appreciate the complexities of the study and its consequent fascination.

ECONOMIC GEOLOGY¹

While the district under consideration is bordered on the east by an area in which hematite, pyrite, galena and talc have been, or are being, mined, none of them have been found in anything like workable quantity within the limits of the map. The ferruginous quartz schists of the Grenville are present in quantity but are very lean ores indeed. One mile north of Theresa on the Red lake road a small opening has been made on a hematite mass which occurred as a direct replacement of Grenville limestone. The material was a finely crystalline, scaly, specular iron, and was of great purity, but there were only a few tons of it. While therefore the deposit was of interest as a clear and pretty example of replacement of the sort, it had no economic value.

¹ By H. P. Cushing.

Small masses of barite are not infrequent in the Grenville limestone, but none were seen of any size or importance. An old opening was made on a coarsely micaceous limestone contact zone, 2 miles north of Theresa, but no mica of merchantable size and quality was forthcoming.

The only mineral industry of the district that has any present or prospective value is the quarry industry. Stone has been and is being quarried for road metal, for paving, for flagging, for lime, and for construction. Various Precambrian rocks, the Potsdam sandstone, and the Pamela, Lowville and Black River limestones have all been quarried in varying degree for one or the other of these purposes.

Road metal

Road improvement is going on hereabout, as elsewhere in the State. About Theresa, Grenville limestone has been chiefly used, though a small quarry has been opened in very impure limestone cut up by granite, which furnished very variable, and hence not very good material. The limestone from the other quarry makes a very good macadamized road, as would apparently much of the Grenville limestone of the district.

About Alexandria bay various experiments have been tried with road metal. The Laurentian granite gneiss of the vicinity has been used, and of course given poor satisfaction. To a small extent Pamela limestone has also been used, and has not proved very satisfactory, probably because of the variability of the different layers used, pure limestone and magnesian limestone probably being mixed together. At present a considerable stretch of road north of Browns Corners is being macadamized with Grenville amphibolite, obtained 1 mile west of Redwood, surfaced with Grenville limestone, which, as we saw it being obtained, was of poor quality. The amphibolite was slightly soaked with, and cut by granite, so that the material was not as uniform as is desirable, but the quantity of granite is so slight that the lack of uniformity is not prominent, and the amphibolite itself is quite undecayed, firm and strong. It seems on the whole likely to prove quite adaptable to road-making purposes. Its composition is quite similar to that of trap, and in all probability it will bind in similar fashion.

Potsdam sandstone has been used as a road rock to a small extent. It is absolutely unfitted for such use, and the worst rock that could be selected for the purpose.

In the southern part of the mapped district the Lowville, Black River and Trenton limestones have been used on the roads, and all serve the purpose very well.

The rock of the district best fitted for road metal has, as yet, not been utilized at all, namely that of the trap (diabase) dikes. There is no better road metal known than trap, provided it be unrotted, and the wide dikes which occur on Grindstone island are capable of furnishing a considerable supply of material, much of which is certainly quite fresh. The material is in large demand for road-making purposes.

On the country roads to the eastward of Alexandria Bay, on which travel is light, the easily rotting, aluminous phases of the ferruginous quartzite (Grenville) have had considerable use for surfacing the roads, and answer the purpose satisfactorily.

Granite quarries

During the past season both the Picton granite and the Laurentian were being quarried in the district. The former rock has been intermittently quarried on Grindstone island for a number of years and has been considerably used for structural and ornamental purposes, both locally and at a distance. For uses for which pronouncedly red granites are serviceable it compares very favorably in appearance and quality with the other red granites of the country. There is much quite uniform material available, and large sized blocks can be quarried. In 1908 none of the Grindstone island quarries were being worked, though quarrying was actively in progress on Picton island, where the chief quarries of today lie.

On the mainland, a short distance west of Alexandria Bay, active quarrying operations are in progress in the Laurentian granite gneiss. At the location the rock is fairly uniform and free from inclusions, and is being quarried for paving blocks, which are being shipped to Chicago for use. Transportation to the various cities on the Great Lakes is of course cheap, and the rock seems well adapted to the purpose for which it is being used.

Sandstone quarries

Various small openings have been made in the Potsdam sandstone here and there in the district, for very local building and flagging purposes. Just beyond the Alexandria sheet edge, to the east, in the town of Hammond, the Potsdam forms a long scarp, at the base of which the railroad runs, and the rock here is quarried largely

for paving blocks. It is fairly evenly and thinly bedded here, mostly of red color, well indurated, and quite well adapted to the purpose. The same would be true of much of the Potsdam of the adjacent portion of the Alexandria sheet, were it as conveniently situated as regards transportation.

Limestone quarries

There are many of these in the district, quarrying the Pamela, Lowville and Black River limestones, both for structural purposes, and for burning for lime. The massive 7 foot tier of the Black River is largely quarried, the large solid blocks obtainable rendering it an exceedingly serviceable material for heavy masonry construction, much more so than the thinner bedded Lowville and Pamela limestones. Some of the beds of the upper Lowville are also fairly thick, make very serviceable stone where construction is less massive, and hence are quarried in many places. Most of the Pamela is much thinner bedded, and the thicker beds are mostly separated from one another by much thin bedded material. Nevertheless the formation contains some good stone, and there are numerous quarries in it all the way from Leraysville to west of Clayton, which, however, chiefly serve a local use in the northern part of the mapped area. It is not so largely quarried and used as the upper Lowville. The dove limestones of the upper part of the formation should, it would seem, make an excellent cement rock.

A single quarry has been opened in the impure, thin beds of the upper division, a few miles south of Clayton, and the stone used for flagging in Clayton. Owing to the joints only medium sized slabs can be obtained, but otherwise the rock is fairly smooth surfaced and makes a very respectable flagstone.

The quantity of limestone in the district available for these various uses is enormous, and the nearness of water transportation bespeaks a considerable future for the industry.

PETROGRAPHY OF SOME PRECAMBRIC ROCKS¹

It is proposed here to treat, in somewhat more detail than seemed suitable in the general account, of certain of the Precambrian rocks with discussion of chemical analyses. While some of the igneous rocks of northern New York have already received detailed study, more especially the syenites and certain gabbros, others have been comparatively neglected, notably the granites. For the purpose of

¹ By H. P. Cushing.

somewhat atoning for this neglect, analyses have been prepared of four samples of granites of the region, as shown in the following table:

	1	2	3	4	5	6
SiO ₂	76.56	76.41	73.33	73.10	70.13	66.59
Al ₂ O ₃	12.95	12.41	13.55	14.29	15.47	14.54
Fe ₂ O ₃.....	.16	1.01	.58	1.04	1.52	2.42
FeO.....	.37	.50	1.53	1.04	1.05	2.43
MgO.....	.24	.46	.45	.53	.85	1.18
CaO.....	1.30	.78	1.66	1.18	1.60	2.15
Na ₂ O.....	3.90	3.34	5.01	3.08	3.72	3.08
K ₂ O.....	4.23	4.33	3.12	5.36	4.39	5.62
H ₂ O +.....	.25	.34	} .45	{ .54	.48	.46
H ₂ O -.....13			.07	.01
TiO ₂.....	.06	.03	.17	.18	.30	.81
ZrO ₂.....	.....	.02	.....	.....	.....	.....
P ₂ O ₅.....	.....	.....	.....	.03	.....	.40
Cl.....	.04	.....	.....	.03	.05	.03
F.....	.03	.01	.....	.02	.09	.06
S.....	.02	.01	.....	.02	.07	.08
MnO.....	.02	.06	.04	.07	.08	.23
BaO.....	.02	.....	.....	.....	.05	.17
	100.15	99.84	99.89	100.58	99.86	100.25

NOTE. Cr₂O₃ and CO₂ absent in nos. 1, 4, 5 and 6.

1 White (bleached) granite near limestone, 1 mile north of Redwood (5K10, Alexandria sheet), from a small boss of Laurentian granite gneiss. Analysis by E. W. Morley.

2 Morris granite of Long Lake quadrangle, one of the later granites of the region. N. Y. State Mus. Bul. 115, p. 511.

3 Laurentian granite gneiss from the Methuen bathylith of central Ontario. F. D. Adams, Jour. Geol. 17:17.

4 Laurentian granite gneiss of the Alexandria bathylith, ¼ mile south of Alexandria Bay (6E5, Alexandria sheet), analysis by E. W. Morley.

5 Laurentian granite gneiss of Antwerp bathylith, 2 miles east of Theresa (16M4b, Theresa sheet), chosen for analysis because of apparent slight digestion of amphibolite. E. W. Morley, analyst.

6 Picton granite, from a quarry 1 mile southeast of Grindstone, Grindstone island (2F3, Grindstone sheet). Analysis by E. W. Morley.

That the granite gneisses hold abundant amphibolite inclusions in various stages of digestion, so that the rock is quite variable in composition, has already been stated. The rock of analysis 4 was carefully selected as representative of the normal, acid phase of the rock, free from amphibolite contamination. It is a quite normal, rather acid granite, and comparison with analysis 3 shows close agreement except that the relative proportions of the alkalis are

reversed in the two. Calculation of its norm gives the following result:

Or	31.69	} 95.29	Class 1, persalane
Ab	26.20		Order 4, britannare
An	5.00		Rang 2, toscanase
Co	1.50		
Qz	30.40		
Ily	2.46	} 4.44	Subrang 3, toscanose
Il & Mt	1.98		

The rock of analysis 5 was not the normal acid granite gneiss of the locality where it was collected, but somewhat darker colored, more basic in appearance, and the field relations definitely suggested that it had soaked up some amphibolite. Nevertheless the analysis shows that this contamination is in slight amount, and the rock is to be classified in the same group as its predecessor, as its calculated norm shows.

Or	26.13	} 93.85	Class 1, persalane
Ab	31.44		Order 4, britannare
An	7.51		Rang 2, toscanase
Co	1.83		
Qz	26.94		
Hy	2.50	} 5.49	Subrang 3, toscanose
Il & Mt	2.70		
Py	0.29		

The mode of these rocks differs so little from the norm that it is not thought worth while to present the calculation. Both rocks consist chiefly of feldspars and quartz, with biotite as the principal additional mineral, a little magnetite, and trifling amounts of apatite, zircon, titanite, muscovite and pyrite. These minerals taken together only amount to about 6% in the first case and 8% in the second. In each case the surplus of alumina in the norm, calculated as corundum, is in just the proper amount to combine with the magnesia to form biotite.

Bleached granite

The rock of analysis 1 is from the margin of a small granite boss-cutting limestone, north of Redwood, which we regard as being of Laurentian age, and is a fresh sample of granite whitened by adjacent limestone. It is a somewhat more acid rock than the preceding. Unfortunately no samples which seemed satisfactory

for analytical purposes could be obtained from the adjacent red granite of the same boss, and this white granite stands as the only border rock of any of the granites which has been analyzed. The field relations of all the granite masses indicate that their border zones, and the dikes which run out from them, are more acid than the general mass of the rock, higher in quartz and with much less biotite and magnetite. Now the granite cuts and sends dikes into all the Grenville rocks, all of this more acid phase, yet it is only in the case of adjacent limestone that the border and the dikes become white. In the schists and quartzites they remain red, though equally acid with the white. In so far then as the higher silica and lower iron of the white granite are concerned, the rock is believed to be merely an average representative of the general, more acid border rock, it being confidently held that much of the red, border granite or dike granite would show equivalent acidity, and like diminution in iron, and that the color change is in no way concerned in these differences. Though no chemical analyses are available, study of slides of these acid red granites gives results in close accord with the analysis of the white, and many of them show almost no biotite and magnetite in the rock, hence they are much poorer in iron than the rock of analysis 4, though with feldspar equally as red in color. Slight differentiation has taken place in the granite, producing more acid borders and dikes, and these bleached only by limestone.

The rock classes as a toscanose, as do the others. Yet it is close to the border line between orders 3 and 4, as shown by its close similarity in composition with the red, Morris granite of analysis 2, which falls in order 3 and is an alaskose.

There is every reason to believe that the coloring matter of the red feldspar is ferric oxid; in fact in some of the thin sections, minute, red hematite scales are readily made out with high powers. In casting about for some chemical explanation of the bleaching of the feldspar, chance put me in communication with Dr W. F. Hillebrand, who most generously furnished me such data as he had at command. He writes as follows:

Many years ago, in Denver, I had occasion to analyze a zeolite that was colored red by iron oxid. On ignition the red color disappeared entirely and almost pure white resulted. This was undoubtedly due to a combination between the iron oxid and the silicate material. My impression is that the zeolite was, a calcium-aluminum silicate. Since then I have seen in the *Chemical News*, vol. 84, p. 305, a reference to the decolorizing effect of alumina on ferric oxid when the two are ignited together . . .

Now on hearing of your problem it occurred to me that such an effect might be represented by the bleached dikes in limestone. The idea was that, under the influence of the intrusions, the limestone may have become decarbonated to a slight extent, thus facilitating action with the ferric oxid of the feldspar. The explanation does not, however, satisfy me, for one might expect perhaps that the feldspathic material intruded at the elevated temperature would have already acted on its iron oxid, and hence not show color; still it may be that the silicate molecule of the feldspar is far more resistant than the zeolite and limestone in respect to ferric oxid, which might thus be in independent existence with the feldspar at high temperatures.

Dr Warth's article in the *Chemical News* deals with the blowpipe ignition of mixtures of alumina and ferric oxid in various proportions, in which the color invariably changed from red to white when small amounts of iron were used, while a brownish tint was obtained when the proportions were larger. Incidentally it was also shown that the alumina prevented reduction of the iron to the magnetic oxid.

A sample of finely crushed and sorted red granite was ignited by us for three hours over a Bunsen flame in a platinum crucible. The portion in close contact with the sides and bottom became white, while the bulk of the material, in more central position and hence less strongly heated, retained its red color. This we take to indicate that, with sufficiently high temperature, even in feldspar, the red color will disappear, and that the presence in rocks of alkali feldspar colored red by ferric oxid shows that, under the conditions of congelation, the temperature was not sufficiently high to bring about this color change. We then mixed a small quantity of powdered limestone with another charge of the crushed granite, and ignited in the same crucible over the same burner for the same time. Not only was the feldspar of the entire charge bleached, but the bleaching seemed complete at the end of one hour. Finally we ignited a third charge, in which a very thin coating of limestone was spread over the top, but not mixed with the granite as in the previous case, and here again the bleaching was prompt and absolute. It is not intended to imply that the cause of the bleaching was the same in both cases, but only that, in the presence of lime, decoloration took place more readily and at a lower temperature; precisely what the field relations had indicated for the granite in place. There is also here, it seems to us, a hint at the reason why red coloration is a common feature in alkali feldspars, and not in lime soda feldspars.

The amount of ferric oxid in the red feldspar is undoubtedly very trifling, so that, if chemical combination has taken place and the lime has entered into the reaction the quantity involved is so small that it would be a comparatively insignificant feature in the complete rock analysis. It is to be noted that the lime is somewhat higher in analysis 1 than in 4, but, while it is possible that this is owing to lime taken up from the limestone and going into combination with the iron of the feldspar, it must be remembered that the variation is well within the limits of variation which all the bases show in the general granite mass, hence it is absolutely unsafe to generalize in regard to it. We may have a combination of lime, iron and alumina in a spinellike mineral, though lime does not, in general, occur in spinel; or a small amount of anorthite may be formed, with the iron replacing alumina. The iron may perhaps be reduced, forming an iron aluminate; the iron reduced to the ferrous condition, though it would seem as if this would likely give a green color to the feldspar. Warth argues that his color changes need not mean chemical combination of the two oxids but rather a diffusion of one in the other. Hillebrand, however, is quite confident that combination takes place. He says, "It is unquestionable that both lime and alumina decolorize and combine with ferric oxid when they are heated together." Though this chemical question must be left indefinite, it does seem to us certain that the red color of the feldspar may be made to disappear merely by sufficiently high and prolonged heating, that the presence of lime facilitates the process, lowering the necessary temperature, and that with our feldspars here the temperatures were not sufficiently high to discharge the color, or rather to cause the feldspars to crystallize with the iron combined, rather than as free hematite, under the conditions prevailing at the place and time of solidification; though they were high enough to cause the combination to take place when in the vicinity of limestone and under its influence.

The only difference in the mineralogy of the two rocks is the presence in the white rock of occasional, scattered, small black tourmalins, which in general do not appear in the other, though they are locally present even there. They would seem attributable to the presence of mineralizers in the border phase of the granite, and in the dikes they occur in the red granites adjacent to other rocks than limestone, such as quartzite for example, and seem to have nothing whatever to do with the color change. It seems to us that the chemical analysis gives no suggestion whatever as to the cause of this change.

Picton granite

The specimen of Picton granite analyzed was selected as an average representative of the rock, and bears out the impression gained in the field that as a whole it is less acid than the Laurentian granites where uncontaminated by Grenville material. It seems less quartzose, and always shows considerable hornblende, which is relatively scarce in the granite gneiss. The thin section shows it to be fairly rich in accessory minerals, titanite and apatite especially being frequent and fairly coarse, the former particularly so. Some pyrite is present, zircon also, little hematite inclusions in the feldspars, and ilmenite or rutile needles in the quartz. A few minute tourmalin crystals also occur. The green hornblende is altering to biotite, and there is additional biotite in the rock as well. For the feldspars, microperthite, microcline, microcline-microperthite and oligoclase are all present in considerable amount, and all with strongly marked characters. A good deal of micropegmatite, some of it quite coarse, is also to be seen. Altogether, in its minor mineralogy, the rock presents considerable contrast to the granite gneiss.

The norm of the rock is as follows:

Or....	33.36	} 89.00	Class 1, persalane
Ab....	26.20		Order 4, britannare
An....	8.62		Rang 2, toscanase
Qz....	20.82		
Hy....	4.48	} 10.64	Subrang 3, toscanose
Mt....	3.48		
Il....	1.52		
Py....	0.15		
Ap....	1.01		

It thus falls in the same rock group as the granite gneisses, but is much nearer the border of the group than they are. The greater variety and abundance of the femic and alferric minerals, hornblende, biotite and titanite, would cause the mode to depart somewhat more widely from the norm than in the previous cases, the lime to form titanite being deducted from the anorthite, releasing alumina for the biotite and diminishing the quartz percentage.

The dike phases of this granite range more acid than this, but with this exception it is thought that the average of the rock composition is well represented by the analysis. The composition is

toward the basic end of the granites, hence it is not surprising that slight variations toward further basicity should give rise to rock with little quartz, like that south of Clayton along French creek. Except for this the petrographic agreement is so close in all details that there seems no question as to the identity of the two rocks.

Alexandria syenite

In the previous description of this syenite it has been stated that an augen gneiss adjoins it on the south which was taken by us in the field for a gneissoid, border phase of the rock, but that Smyth dissents from this view. In the field this border rock appears much the more basic of the two, but closer examination shows the presence of much quartz, and chemical and microscopic investigation shows it to be much more acid than the syenite. Analyses of each follow, with two analyses of the general Adirondack green syenite, thought to be represented in this district by the Theresa syenite, (of which no analyses have been made) for purpose of comparison with them.

	1	2	3	4	5
SiO ₂	58.99	59.70	63.45	66.50	66.59
Al ₂ O ₃	19.22	19.52	18.38	15.66	14.54
Fe ₂ O ₃	2.83	1.89	1.09	1.75	2.42
FeO.....	2.83	4.92	2.69	2.21	2.43
MgO.....	1.25	.78	.35	1.18	1.18
CaO.....	3.41	3.36	3.06	2.15	2.15
Na ₂ O.....	4.33	5.31	5.06	3.74	3.08
K ₂ O.....	5.64	4.14	5.15	5.02	5.62
H ₂ O +.....	.35	} .52	.30	{ .40	.46
H ₂ O—.....	.04				
TiO ₅.....	.01	.....	.07	.71	.81
P ₂ O ₅.....	.59	.....	.....	.59	.40
Cl.....	.10	.....	.....	.06	.03
F.....	.40	.....	.....	.05	.06
S.....	.08	.....	.....	.18	.08
MnO.....	.14	.9	trace	.03	.23
BaO.....	.09	.....	.....	.05	.17
	100.30	100.23	99.60	100.33	100.25

1 Alexandria syenite, 3½ miles north of Redwood (8K2, Alexandria sheet). E. W. Morley, analyst.

2 Tupper syenite (laurvikose), N. Y. State Mus. Bul. 115, p. 514.

3 Loon Lake syenite (pulaskose), N. Y. State Mus. Bul. 115, p. 514.

4 Augen gneiss associated with Alexandria syenite, 2 miles west of north of Redwood (6J2, Alexandria sheet), E. W. Morley, analyst.

5 Picton granite, repeated from previous column of analyses.

Norm of Alexandria syenite, analysis 1:

Or....	33.36	} 87.15	Class 1, persalane
Ab....	36.68		Order 5, Canadare
An....	11.12		Rang 2, pulaskase
Co....	1.85		Subrang 3, pulaskose
Qz....	4.14		
Hy....	5.00	} 11.30	
Mt....	4.18		
Fl....	0.78		
Ap....	1.34		

The rock itself contains considerable green hornblende and biotite which, together with the accessory magnetite, titanite, apatite and pyrite, constitute about 15% of the rock, (elsewhere they run up to 25 or 30%, carrying the rock into the dosalane class) meaning of course that some of the lime, alumina and potash calculated with the salic minerals of the norm are in the hornblende and biotite. Microcline, micropertthite and oligoclase are all present in some quantity, plagioclase being somewhat in excess. Some of the micropertthite is secondary after oligoclase. The rock has beautiful cataclastic structure, showing much more crushing than the Picton granite. Chemically it is seen to be very close to the green syenites of similar silica percentage, the chief difference being in the higher magnesia and in the relative proportions of ferric and ferrous iron and of the alkalis. The higher magnesia expresses itself mineralogically in the formation of hornblende and biotite, instead of the pyroxenes of the green syenite. The general rock is somewhat more basic, and with a higher percentage of ferro-magnesian minerals than the normal green syenite.

The augen gneiss of analysis 4 is a much more acid rock, a toscano, suggesting caution in attempting to account for it as a phase of the syenite. The analysis is so close to that of the Picton granite of the last column as to be almost grotesque. Quite certainly it has no relation whatever to the Picton granite, though mimicing it so closely chemically. The green syenites of the region show wider range of variation than that shown in this case, nevertheless the intrusion here is of such comparatively small size that variation in composition to this amount would be quite unusual. Hence the analyses rather tend to reinforce Smyth's conclusion that we really have here two separate small intrusions, side by side.

Mineralogically the augen gneiss consists of quartz, feldspars and biotite, with accessory magnetite, titanite and apatite, and

small amounts of hornblende, muscovite, zircon and pyrite. The femic minerals constitute 15% of the rock analyzed. The feldspar is chiefly microcline and oligoclase, though with some microperthite. Both feldspars occur as augen, with trains of granulated material running away from them, between which are foliae of quartz, feldspar and biotite. To a considerable extent the quartz and biotite seem to have resulted from recrystallization of feldspar.

The certain Alexandria syenite runs into very gneissoid and micaceous border phases, which lie between its massive core, and the augen gneiss beyond. These varieties are much more micaceous, and much more quartzose than the massive portion, and in them also much biotite and quartz have resulted from feldspar recrystallization. They are thus very similar to the augen gneiss. It was this apparent gradation from one rock to the other in the field which gave us the impression that the whole represented a single intrusion. It is a matter of very minor importance in the local geology, and must for the present be left as undetermined.

Granitized amphibolite and amphibolitized granite (soaked rocks)

Practically all observers who have worked in Laurentian areas, have seen and recorded the evidences, which meet one on every hand, of the attack of the granite upon the amphibolite inclusions, large and small, which occur nearly everywhere, and are often abundant. The action consists of an injection of granite into the amphibolite, at first along the foliation planes, from which the granite spreads out more or less into the adjacent rock, injecting itself between and inclosing the grains, but with the distinction between the two materials still sharp. In later stages this sharpness disappears, the two materials seem to merge, or fade into one another, and as a final stage a rock is produced which seems a true mixed rock, in which a distinction between the two elements is no longer possible, and whose origin would be problematic except for the occurrence of the less advanced phases of the change. Needless to say the granite must be very thoroughly molten in order to produce these mixed rocks. It was our purpose to investigate these rocks somewhat thoroughly chemically. Unfortunately however no material which seemed to us sufficiently fresh to warrant chemical investigation was obtained from rocks which seemed distinctly intermediate. A beginning was made, however, by the investigation of two rocks, one a granite slightly tintured with amphibolite, and the

other an amphibolite slightly soaked by granite, and their analyses appear herewith. Each, in the field, was classified as plainly a soaked rock, in which the constituents were merged. Each was also merely a phase in a gradual increase in amount of soaking, plainly to be traced in the field, and the two samples were chosen from among many because of unusual freshness.

	1	2	3	4	5
SiO ₂	73.10	70.13	56.58	51.42	50.83
Al ₂ O ₃	14.29	15.47	15.54	17.42	18.64
Fe ₂ O ₃	1.04	1.52	3.80	3.64	2.84
FeO.....	1.04	1.05	5.41	5.14	5.97
MgO.....	.53	.85	2.77	5.11	4.90
CaO.....	1.18	1.60	4.56	6.76	7.50
Na ₂ O.....	3.08	3.72	2.91	3.74	4.22
K ₂ O.....	5.36	4.39	4.25	3.33	1.83
H ₂ O +.....	.54	.48	.80	.74	} 1.40
H ₂ O—.....	.07	.01	.10	.09	
TiO ₂.....	.18	.30	1.71	1.25	1.10
ZrO ₂.....	.....	.....	.01	.01	.....
P ₂ O ₅.....	.03	.....	.87	.71	.....
Cl.....	.03	.05	.12	.13	.03
F.....	.02	.09	.14	.10	.....
S.....	.02	.07	.44	.23	.01
MnO.....	.07	.08	.09	.16	.10
BaO.....	.....	.05	.08	.13	.11 CO ₂
	100.58	99.86	100.18	100.11	99.48

NOTE. Cr₂O₃ and CO₂ absent.

1 Laurentian granite gneiss of Alexandria bathylith, from column 4 of original table.

2 Laurentian granite gneiss of Antwerp bathylith, slightly soaked with amphibolite, column 5 of original table.

3 Amphibolite, somewhat soaked by granite, from railroad cut 4 miles north of Redwood (8L2a, Alexandria sheet). E. W. Morley, analyst.

4 Amphibolite, from same railroad cut (8L2B, Alexandria sheet). E. W. Morley, analyst.

5 Amphibolite described by Adams as representing the extreme stage in the alteration of crystalline limestone into amphibolite by contact action of the Glamorgan bathylith, Jour. Geo. 17:2.

It is not thought that the amphibolite of analysis 4 is an altered limestone, but rather a member of the schist series, though likely a calcareous shale, even perhaps an impure limestone. In any case its similarity in composition with the amphibolite described by Adams from Maxwells Crossing is quite striking, the somewhat higher magnesia and potash being the most prominent differences.

Adams also shows, in his valuable paper, the similarity in composition of his contact amphibolite with other amphibolites, even some of igneous origin. It would seem therefore that we are reasonably safe in assuming that analysis 4 will not depart widely in composition from most of the amphibolites of the region, no matter what their origin.

The analyses of the two granites have been already discussed. No. 2 does not depart widely from no. 1 in composition, and might well represent a simple variant of the magma. Its field relations, however, preclude that supposition and it is to be noted that, when compared with analyses 1 and 4, it represents an intermediate stage in every single important constituent. On the basis of the silica percentage a mixture of six parts of analysis 1 and one part of analysis 4 would almost give a rock of the composition of analysis 2. Calculated on that basis the following result is arrived at:

	1	2	3	4
SiO ₂	70.13	70.05	56.58	56.62
Al ₂ O ₃	15.47	14.73	15.54	16.66
Fe ₂ O ₃	1.52	1.42	3.80	3.01
FeO.....	1.05	1.63	5.41	4.14
MgO.....	.85	1.18	2.77	3.97
CaO.....	1.60	1.99	4.56	5.53
Na ₂ O.....	3.72	3.17	2.91	3.58
K ₂ O.....	4.39	5.08	4.25	3.79

In column 1 are given the percentages of the soaked rock shown by analysis, and in 2 the calculated percentages on the basis stated above. They seem to us to be sufficiently alike in every constituent to afford a strong probability that the field relations were correctly interpreted, and that the rock is a true soaked rock. The greatest variation between the two is in the alkali percentages, and these are just the ones which vary most in the general granite masses. The total amount of alkalis, however, is much the same in each, 8.11% in the first case and 8.25% in the second.

The granitized amphibolite is not so definitely a soaked rock as the other, since the amount of granite in it is so small, that it is an impregnated, rather than a mixed rock. Nevertheless the granite is thoroughly disseminated through it, though granitizing it in patches rather than uniformly. Column 3 gives the rock percent-

ages of this amphibolite, and column 4 a calculated mixture of granite and amphibolite in the ratio of 24% of the former and 76% of the latter. The agreement in this case is not so close as in the former one, but in large part the differences can be ascribed to the fact that the granite here is not normal, but of the pegmatitic type, higher in mineralizers and in iron, and poorer in alumina, lime and magnesia than the normal rock. Comparison of analyses 3 and 4 seems definitely to suggest this, the iron being higher in the granitized rock than in the amphibolite, and the lime and magnesia much lower. It is thought that if an analysis of the neighboring granite was available for use in the computation, the agreement would be much closer. But the result is somewhat disappointing, and the importance to be assigned to the discrepancies a debatable matter, likely to vary with the personal equation of the reader. Considering all the circumstances the agreement seems to us as close as could be hoped for, and indicative of the correctness of interpretation of the field evidence, namely, that these are true mixed rocks.

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Education Department Bulletin

Published fortnightly by the University of the State of New York

Entered as second-class matter June 24, 1908, at the Post Office at Albany, N. Y., under the act of July 16, 1894

No. 489

ALBANY, N. Y.

FEBRUARY 15, 1911

New York State Museum

JOHN M. CLARKE, Director

Museum Bulletin 146

GEOLOGY OF THE NEW YORK CITY (CATSKILL) AQUEDUCT

STUDIES IN APPLIED GEOLOGY COVERING PROBLEMS ENCOUNTERED
IN EXPLORATIONS ALONG THE LINE OF THE AQUEDUCT FROM
THE CATSKILL MOUNTAINS TO NEW YORK CITY

BY

CHARLES P. BERKEY

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New York State Education Department
Science Division, April 6, 1910

Hon. Andrew S. Draper LL.D.
Commissioner of Education

SIR: The extraordinary engineering operations which have been undertaken in the effort to provide the city of New York with an adequate water supply have illuminated in most unexpected manner the geological structure and history of the region of the Hudson valley south of the Catskill mountains. So broad has been the scientific scope of this engineering problem and so direct its dependence on geological structure that the Commissioners of the New York City Board of Water Supply early found it of essential moment to enlist in their service a corps of trained geologists.

In 1909 an agreement was effected between the Board of Water Supply and the State Geologist, in pursuance of which the geological data acquired in the preliminary and final surveys for the aqueduct were intrusted to Dr Charles P. Berkey, a member of the staff of the board as well as of the geological survey, for summation and presentation of their broader and more important bearings.

I transmit to you herewith Dr Berkey's report thereupon, entitled *Geology of the New York City (Catskill) Aqueduct*. It is a document of high value not only in enlarging and perfecting our knowledge of the geological structure of the commercial center of the United States, but its data and conclusions must prove of profound importance to all large engineering and architectural propositions concerned with the region of the lower Hudson valley.

I therefore submit this, subject to your approval, for immediate publication as a bulletin of the State Museum.

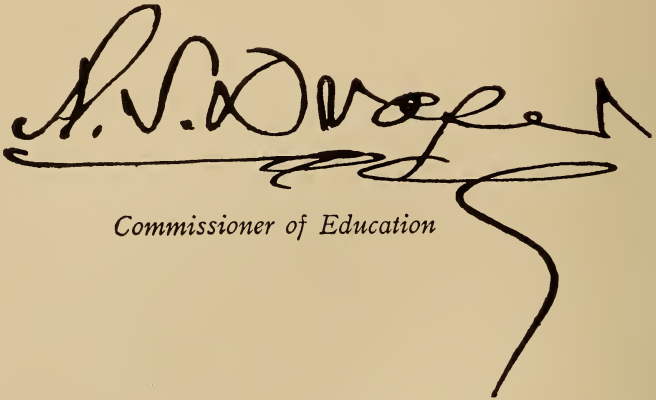
Very respectfully

JOHN M. CLARKE

Director

State of New York
Education Department
COMMISSIONER'S ROOM

Approved for publication this 7th day of April 1910

A large, stylized handwritten signature in black ink, appearing to read "A. V. Wagner". The signature is written in a cursive style with a long, sweeping underline that extends to the right and then curves downwards.

Commissioner of Education

Plate I



The Catskill and Croton water supply systems of New York city

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EXPLORATIONS ALONG THE LINE OF THE AQUEDUCT FROM THE
CATSKILL MOUNTAINS TO NEW YORK CITY

BY

CHARLES P. BERKEY

INTRODUCTION AND ACKNOWLEDGMENT

It is the writer's hope that the series of studies brought together in this bulletin may help to effect a wider appreciation of the practical usefulness of geology. The volume contains a summary of the local geologic facts and the general principles found helpful in solving some of the problems encountered in a single great engineering enterprise. The summary is accompanied by brief discussions of the methods employed and of the final results or conclusions reached. It is therefore essentially a study in applied geology.

Seldom has so favorable an opportunity been afforded to follow extensive exploratory work and check geologic hypothesis or theory by subsequent proof. And still more seldom have engineers in charge of similar works so fully appreciated the value of geologic investigations and the extent to which they can be utilized as a guide.

More credit is due to Mr J. Waldo Smith, chief engineer of the Board of Water Supply of the City of New York, than to any one else for appreciating the importance of the geologic complexity of

the Catskill Aqueduct problem. His exceptional insight into its nature led to the adoption of measures in this direction that are now proved to have been fully justified. A staff of geologists has been maintained. From time to time engineers of the regular staff who have shown unusual aptitude in such investigations have been assigned to special duty on geologic exploratory work. In the preliminary investigations of the Northern Aqueduct, Division Engineer James F. Sanborn was very intimately connected with the geologic work. With him the writer worked out many field studies that later formed the basis of advisory reports, covering locations, kinds of explorations to be made, and interpretations of data. No one has had a better grasp of both the geologic and the engineering aspects than Mr Sanborn. It is with great pleasure that the writer acknowledges many valuable suggestions and much help through association with him. In the later exploratory work within the city similar service has been rendered by Mr John R. Healey, who has much to do with the geologic detail of the delivery conduit data. The consulting geologists employed by the board were Professors James F. Kemp, W. O. Crosby and the writer.

A special debt is acknowledged to Prof. James F. Kemp, consulting geologist of the board, whose confidence in the writer's work originally brought him into touch with these investigations as an assistant, and with whom since that time many joint reports to the board have been written.

Valuable advice and assistance in arranging for the issue of this report has been given by Department Engineer Alfred D. Flinn of Headquarters Department. For some of the corrections and suggestions special acknowledgment is made to Department Engineer Thaddeus Merrimar.

The department engineers, Robert Ridgway of the Northern Aqueduct, Carlton E. Davis of the Reservoir, Merritt H. Smith, formerly of the Southern Aqueduct, Frank E. Winsor of the Southern Aqueduct, William W. Brush and Walter E. Spear of the City Delivery have given every facility for gathering geologic data within their territory and have contributed largely to the better understanding of their special fields.

The geologic matter relating to special problems has been worked out with the aid of the division engineers in direct charge in the field. Among these must be mentioned L. White of the Esopus division, William E. Swift of the Hudson river division, A. A. Sproul of the Peekskill division, Lawrence C. Brink of the Wall-

kill division, J. S. Langthorn of the Ashokan reservoir, Wilson Fitch Smith of the Kensico division, T. C. Atwood of the New York city delivery division.

The data included in the tabulation of this bulletin have been gathered largely by others. Many of the explanations and conclusions are the outgrowth of the work of engineer and geologist, together. A large number of associates are engaged on this public work in such relations to one another that the individuality of each is obscured in the common effort to reach an enviable efficiency and success for the whole enterprise.

The combined efforts of many, unselfishly given, have thus brought together a total far in excess of what any one individual could accomplish. Acknowledgments should therefore be made to those members of the staff of the Board of Water Supply who can not in the nature of the case be mentioned by name. Were it not for their cooperation the great mass of data here summarized could not have been compiled.

CHARLES P. BERKEY

*Special Geologist, New York State Geological Survey;
Consulting Geologist New York City Board of Water Supply
Columbia University, New York City November 1, 1910*

I

GENERAL FEATURES

CHAPTER I

CATSKILL WATER SUPPLY PROJECT

New York city obtains its chief water supply from the Croton river watershed. Other sources¹ now drawn upon are less important although some of them, such as the Long Island underground supply, are capable of considerable additional development. The average daily consumption of Croton water was approximately 324,000,000² gallons for 1907. At the present rate of increase of population the consequent daily increase in consumption of water is 15,000,000 gallons in each succeeding year.

The entire daily flow of water in the Croton river for the 18 years from 1879 to 1897 averaged only 348,000,000 gallons. About 10,000,000 gallons per day is lost by evaporation and seepage from existing reservoirs. The records for 40 years, from 1868 to 1907 make a somewhat better showing. Making no allowance for evaporation the average flow amounts to 402,000,000 gallons. With due allowance for evaporation,³ however, this only increases the daily supply as now planned by about 47,000,000 gallons. That is, the possible total additional water within the Croton watershed would suffice for only three years' growth of the city. Much of this additional water belongs to periods of excessive precipitation. To save it would require additional storage facilities for 305,000,000,000 gallons, and, it is estimated, would probably cost \$150,000,000.

¹ Brooklyn is in part supplied by these additional sources which furnished 145,000,000 gallons daily in 1907.

² The figures used here as to consumption and capacity and available supply are taken from the printed statements of the commissioners of the New York City Board of Water Supply in a circular dated April 16, 1908, and are based upon the investigation and reports of the corps of engineers headed by J. Waldo Smith, chief engineer, John R. Freeman and William H. Burr, consulting engineers. The reports of this commission and various others that have had the responsibility of investigating the future supplies for New York city have been drawn upon freely for such data.

³ The average rainfall for the past 40 years is about 49 inches per year. Only about 48 per cent of this runs into the streams. The rest evaporates or is absorbed by the vegetation or joins underground supplies that do not again appear at the surface in the district.

Taking into account the small relief possible in this direction and the certainty that in less than five years the demands of the city will be greater than the total capacity of the Croton watershed, it is clear that some other source of large and permanent supply is an absolute necessity.

In the search for such additional sources, there has been much careful work done by able commissioners.¹ In the meantime, residents of certain districts where there are possible supplies have taken steps by legislative action to effectually² prevent New York city encroaching upon their territory. Criticisms³ of all kinds largely by those only partially informed as to the magnitude and complexity of the problem and partly by those ignorant of the simplest factors in its solution, have been kept perpetually before the public. One needs only a slight acquaintance with such public works to realize that it is much easier and more common to criticize and raise the cry of corruption or incompetence than it is to give really valuable advice or solve a real problem or carry an enterprise of the most vital public importance to a successful issue.

It is sufficient here to observe that exhaustive studies of the whole question of water supply by competent men have resulted in a practically unanimous conclusion that the streams of the Catskill mountains are the most satisfactory, economical, reliable, abundant and available future source of water.

¹ The Report of John R. Freeman C. E., 1899-1900; Report of the Burr-Herring-Freeman Commission, 1902-4; the Studies of the Department of Water Supply, Gas and Electricity, 1902-4; Investigations of the Board of Water Supply, 1905 to the present time.

² Acts of the Legislature of 1903-4.

³ The commonest suggestions neglect the question of permanence or constancy of supply. The following sources are often mentioned, (a) Lake George, forgetting that this beautiful lake has an abnormally small watershed and could never figure as a large permanent supply; (b) artesian wells, ignoring the fact that with the exception of certain portions of Long Island there is almost no artesian capacity, and on Manhattan and the mainland the crystalline rocks make such development useless; (c) Lake Ontario, apparently overlooking the great distance (400 miles) and the many other complications that this international water body involves; (d) the Housatonic river, neglecting the difficulties of interstate origin; (e) Dutchess county, where the city is prohibited by legislative enactment; (f) the Hudson river, ignoring the fact that the Hudson is an estuary of the sea with brackish water of a very impure quality and wholly unfit for domestic uses. It is, however, worth while to note that Hudson river water is sure to be used more and more extensively for fire protection and similar purposes in the more densely populated portions of the city by means of an entirely different system of conduits. This is one of the most promising directions of relief looking to the more distant future.

The Catskill supply will furnish over 500,000,000 gallons of water daily and was estimated to cost \$161,857,000. That is, the additional supplies from the Catskills as planned will, when completed, be sufficient for the increasing demands of the growing city, for the next 35 years. And some of it may be badly needed long before it can possibly be delivered.

Parts of the Catskill system¹

The chief sources within the Catskills now included in the plans of the board are:

- 1 Esopus creek, to be taken at a point near Olive Bridge.
- 2 Rondout creek, to be taken at a point near Napanoch.
- 3 Three small streams tributary to the Rondout.
- 4 Schoharie creek, to be taken at a point near Prattsville.
- 5 Catskill creek, to be taken at a point about 1 mile northeast of Durham.
- 6 Six small streams tributary to the aqueduct between Catskill creek and Ashokan reservoir.

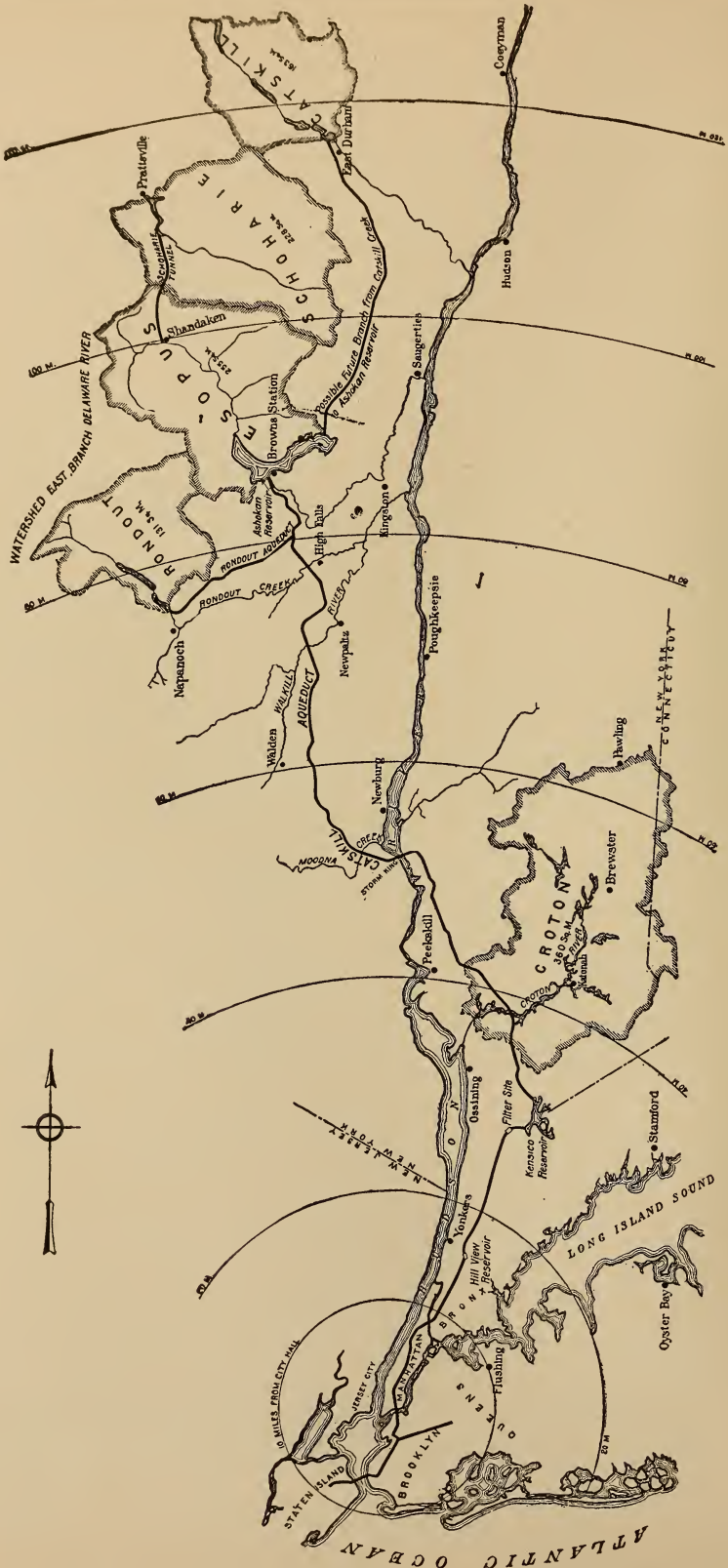
The comparative areas of watershed and their daily capacity are estimated² by the corps of engineers as follows:

	AREA IN SQUARE MILES	STORAGE IN GALLONS	DAILY SUPPLY IN GALLONS
1 Esopus watershed.....	255	70 000 000 000 ³	250 000 000
2 Rondout watershed.....	131	20 000 000 000	98 000 000
3 Three small tributaries.....	45	.....	27 000 000
4 Schoharie watershed.....	228	45 000 000 000	136 000 000
5 Catskill watershed.....	163	30 000 000 000	100 000 000
6 Six small streams.....	82	.....	49 000 000
Total.....	904	165 000 000 000	660 000 000

¹ The subdivisions and proposed locations given here are taken chiefly from the Report of the Board of Water Supply of the City of New York to the Board of Estimate and Apportionment, October 9, 1905.

² Estimates are much more complete for the Esopus, which it is planned to develop first, than for any other streams; and it must be understood that the figures are subject to revision dependent upon modifications of original plans to meet the conditions that develop upon more elaborate investigation.

³ Preparations are to be made for storage of 120,000,000,000 gallons of water on the Esopus, but a part of this capacity is intended to accommodate supplies drawn from other sources than Esopus creek itself.



CATSKILL WATERSHEDS AND AQUEDUCT

Fig. 1 Outline map showing the different catchment basins of the New York water supply system and the Catskill Aqueduct. (By courtesy of the Board of Water Supply)

The evident certainty that present supplies from the Croton and Long Island will be very inadequate long before the Catskill system can be completed has influenced the adoption of plans contemplating the construction of certain parts in advance of the rest. To begin with, only the Esopus watershed is to be developed by the construction of the great Ashokan dam at Olive Bridge making the reservoir of full capacity. At the same time that portion of the aqueduct between the Ashokan dam and the present Croton reservoir is to be completed in advance of other parts so as to make it possible to turn additional supplies into the Croton system, the capacity of the present Croton aqueducts being somewhat in excess of the Croton storage in dry years. It is furthermore desirable that increased storage capacity should be secured much nearer to New York city, and with that end in view Kensico reservoir is to be greatly enlarged. It is estimated that this may be made to hold 50 days' supply of 500,000,000 gallons daily.

The development of the Catskill system is being carried on by the Board of Water Supply, which was appointed by Mayor McClellan, as provided in chapter 724, of the laws of 1905. The present board consists of John A. Bensel, *president*, Charles N. Chadwick and Charles A. Shaw. The Engineering Bureau of the Board is in charge of J. Waldo Smith, as chief engineer, Merritt H. Smith, as deputy chief engineer and Thaddeus Merriman, assistant to chief engineer.

Influenced doubtless in large part by the unity of certain portions of the project, either because their essential engineering features are distinct, or because their construction is more urgent, or in order to facilitate the work of supervision of so great an undertaking, the following departments have been created:

1 Headquarters department (executive). In charge of general designs, plans of construction and preparation of contracts. Alfred D. Flinn, department engineer.

2 Reservoir department. In charge of development of the Catskill watershed and the construction of the various dams and reservoirs. Carlton E. Davis, department engineer.

3 Northern aqueduct department. In charge of the construction of full capacity aqueduct from the Ashokan dam (60 miles) to Hunters brook in the Croton system. Robert Ridgway, department engineer.

4 Southern aqueduct department. In charge of the construction of full capacity aqueduct from Hunters brook in the Croton system

to Hill View reservoir on the northern limits of New York city and of the storage reservoirs and filtration work. Merritt H. Smith, and more recently F. E. Winsor, department engineer.

5 Long Island department. In charge of the development of the underground water supply of Long Island. A plan looking toward this end has been prepared and approved by the city authorities and is now being reviewed by the State Water Supply Commission.

6 City aqueduct division. In charge of the delivery of water from Hill View reservoir throughout Greater New York. Originally in charge of W. W. Brush, now under Walter E. Spear, as department engineer.

Departments are further divided into "divisions" each in charge of a division engineer and a full corps of assistants. The subdivisions of these larger units, although primarily based upon convenience and efficiency of engineering supervision, coincides rather closely with the larger geologic problems included in this bulletin.

Generalities of construction

The chief types of structure projected include (1) masonry dams, (2) earth dikes with core walls, (3) "cut and cover" aqueduct through country of about the elevation of hydraulic grade, (4) tunnels through mountains or ridges that are too high, and (5) pressure tunnels under valleys or gorges that are too low.

Some of these are of record proportions. For some of the details and figures *see* the different special problems in part 2.

All items complete as planned involve a total of:

10 dams

10 impounding, storage and distributing reservoirs

4.5 miles of dikes

54.5 miles of "cut and cover" aqueduct

13.9 miles of tunnel at grade

17.3 miles of pressure tunnel below grade

34 shafts of aggregate depth of 14,723 feet.

6.3 miles of steel pipes making

92.5 miles of aqueduct complete to Hill View equalizing reservoir

1 filtration works

18.0 miles of delivery tunnel in New York city to the terminal shafts in Brooklyn

16.3 miles of delivery pipe lines

Allowing for contingencies and costs for engineering supervision the system is estimated to cost \$176,000,000 and many years will be required for its completion. The present plans, however, contemplate only the immediate development of the Esopus watershed, the storage reservoirs near the city and the main aqueduct to the various points of delivery within the city limits. It is expected that part of this additional supply of water will be available by the year 1913, or early in 1914.

CHAPTER II

PROBLEMS ENCOUNTERED IN THE PROJECT

When the Ashokan reservoir is filled the surface of the stored waters will stand 590 feet above the sea. Hill View reservoir on the northern borders of New York city will have an elevation of 295 feet. The distance between these two points is nearly 75 miles in direct line. The contour of the country and other exigencies of construction will increase this to approximately 92 miles. A main distributary conduit in New York city will add 18 miles more.

The destination of the water therefore before distribution begins is 300 feet lower than its starting point. This is sufficient head to permit gravitational flow and a self-delivering system. If the hydraulic gradient can be maintained it would evidently constitute a decided advantage. The plans have therefore from the beginning contemplated such construction. It means then that a flowing grade must be maintained in all tunnels or channels or tubes and that when a depression has to be crossed the pressure must be maintained in some sort of a conduit so that the water may rise again to a suitable level on the other side.

The difficulties of accomplishing this in a work of such magnitude are not at first apparent. The full significance of the undertaking can be realized only after a study of the country through which the aqueduct must be carried. It then resolves itself into a series of problems, each one having its own characteristics and peculiar difficulties and methods of solution and each requiring a thorough understanding of the topographic features of the vicinity and a working knowledge of geologic conditions.

General questions

It is sufficient at this point to call attention to the facts of the topographic map and point out only the most general physiographic features that may at once be seen to materially modify the simplicity of the line.

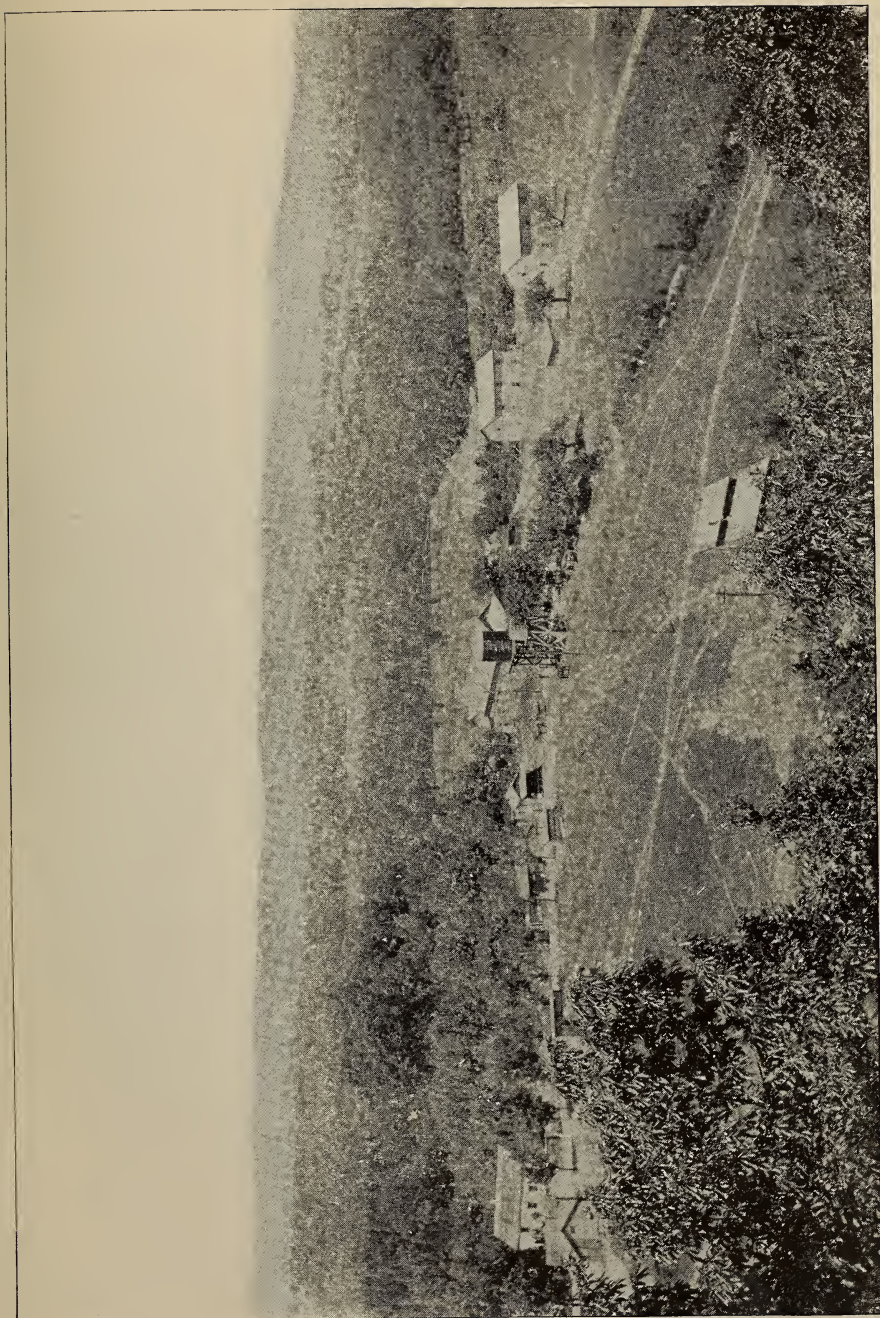
For example, one has scarcely left the great reservoir, with water flowing at 580-90 feet above tide, before the broad Rondout valley is reached, with a width of $4\frac{1}{2}$ miles nowhere at great enough elevation to carry the aqueduct at grade. If it is to be crossed at all, and it must be crossed to reach New York city, some

special means must be devised. If a trestle be proposed, one finds that it would have to be $4\frac{1}{2}$ miles long (24,000 feet), and in some places 300 feet high, and at all points large enough and strong enough to carry a stream of water capable of delivering 500,000,000 gallons daily — a stream that if confined in a tube of cylindrical form would have a diameter of about 15 feet.

A steel tube might be laid to carry the water across and deliver it again at flowing grade, but here one is met with the fact that it would require a tube of unprecedented size and strength and if divided into a number of smaller ones the cost would be greater than that of a tunnel in solid rock.

The other alternative is to make a tunnel deep enough in bed rock to lie beneath surface weaknesses and superficial gorges and in it carry the water under pressure to the opposite side of the valley. This is the plan that seems best suited to the magnitude of the undertaking and would seem to promise most permanent construction. But no sooner is this conclusion reached than it is realized that there are now several hitherto unregarded features that assume immediate and controlling importance. Some of these, for example, are (1) the possibility of old stream gorges that are buried beneath the soil, (2) the position of these old channels and their depth, (3) the kinds of rock in the valley, (4) their character for construction and permanence, (5) the possible interference of underground water circulation, (6) the possible excessive losses of water through porosity of strata, (7) the proper depth at which the tunnel should be placed, (8) the kinds of strata, and their respective amounts that will be cut at the chosen depth, (9) the position and character of the weak spots with an estimate of their influence on the practicability of the tunnel proposition. Then after these have all been considered the whole situation must be interpreted and translated into such practical engineering terms as whether or not the tunnel method is practicable, and at what point and at what depth it should cross the valley, and at what points still further exploration would add data of value in correcting estimates and governing construction and controlling contracts.

This is a general view of one case, the first one of any large proportions in following down the aqueduct. There are many others. In nearly all of them the importance of geologic questions is prominent. Many of them, of course, are of the simplest sort, but, on the other hand, some are among the most obscure and evasive problems of the science. And they do not become any



General view of the Rondout valley looking north along the aqueduct line from the margin of the Shawangunk range toward the Catskills. (Photograph by New York City Board of Water Supply)

easier simply to know that they must ultimately be stated in terms precise enough for the use of engineers, and to know furthermore that the real facts are to be laid bare when construction begins and as it progresses. But from another viewpoint it may be regarded as an exceptionally fine opportunity to study applied geology in its best form and to see the intimate interrelationship between an engineering enterprise of great public utility and a commonly considered more or less obscure science. The services of geology have been seldom so consistently employed in earlier undertakings of similar character. It is to be hoped that the accompanying illustrations of the practical application of geologic knowledge and facts to engineering plans and practice may add to the appreciation of the commonness and variety of such service in many everyday affairs. Furthermore, this unique enterprise, the like of which for magnitude and complexity has never before been attempted, has given to those whose good fortune has brought them into working relations with its problems, the opportunity of a generation in their chosen field.¹ The success stages from isolated observations, inference, hypothesis, theory, conclusions, and fully proven facts are all represented. The steps more or less fully coincide with the degree of confidence observable in the tone of advisory reports to the engineers in charge — representing suggestions, recommendations, or specific advice.

It is one of the cherished wishes of the writer of this bulletin that some of these problems may be presented in such manner as to serve a distinct educational purpose. For this reason in part, deeming it even of greater importance than the mere enumeration of newly discovered facts, the writer has chosen to treat the subject from the standpoint of an instructor illustrating the development of working conclusions. It is certain that not all readers have the same degree of preparation or acquaintance with the subject-matter, and it may therefore be useful to include many things that some may well pass by. No excuse is offered except that such method of treatment, in behalf of the general intelligent public that it is hoped to reach, seems to the author to be advisable.

¹ W. O. Crosby of the Massachusetts Institute of Technology, James F. Kemp and Charles P. Berkey of Columbia University have constituted the staff of consulting geologists throughout most of the exploratory work.

Other problems

The foregoing observations apply likewise to the other larger problems of the aqueduct line. A list of the larger ones requiring extensive exploration and illustrating geologic application in their solution are given below :

- 1 Location of the Ashokan dam
- 2 Sources of material for construction
- 3 Crossing the Rondout valley
- 4 The Wallkill valley
- 5 Moodna buried valley
- 6 Pagenstechers gorge and Storm King mountain
- 7 The Hudson river crossing problem
- 8 The Storm King-Break Neck cross section
- 9 Foundry brook
- 10 Sprout brook notch
- 11 Peekskill creek valley
- 12 Croton lake pressure tunnel
- 13 Bryn Mawr siphon
- 14 The new Kensico dam
- 15 Kensico quarries
- 16 New York city delivery tunnel

In addition to these there are several questions of general bearing in which the chief lines of argument and the chief basis of conclusion are essentially geologic. Although little wholly new data is yet available on these particular questions from any direct work of the aqueduct, yet it will add materially to an appreciation of the far-reaching influence of established geologic data and geologic reasoning to enumerate some of them :

- 17 Continental subsidence and elevation
- 18 Crustal warping
- 19 Postglacial and present faulting
- 20 Underground water circulation
- 21 Relative resistance of the different formations to corrosion by aqueduct waters
- 22 Structural materials

Each of these problems or questions or topics is discussed separately, so far as practicable. By adopting this plan, of course there is a tendency to repetition but this to a certain extent is unavoidable. Some of it is overcome by suitable references to preceding

discussions. Where such cross reference is too cumbersome, the items are repeated in preference to leaving the case obscure. Thus it is hoped to make each case a unit, and the whole series useful and understandable.

Gathering data

In the accumulation of data all the members of the engineering corps¹ as well as the men acting only in a consulting capacity have taken part. Necessarily the bulk of the exact data has been gathered by the men all the time on the ground and whose duty it was to superintend explorations. The care and intelligence with which this has been done is notable. A considerable proportion of the labor of manipulating the accumulated data and interpreting it so as to reach an explanation of conditions and formulate conclusions has been assumed by the consulting men.

Too much credit can not be given to the heads of departments and divisions for the open-handed way in which all needed facts were held available at all times for comparison and guidance toward sound conclusions. The information upon which investigations have been initiated have been chiefly the following:

- 1 The geologic maps and reports of the New York State Survey
- 2 United States topographic maps
- 3 Geologic folio no. 83, New York city folio
- 4 Earlier engineering records and reports
- 5 Reports of special commissions on water supply

¹ In this work, no group of men have had so direct responsibility as the division engineers. The success with which so many complicated explorations were carried out is chiefly due to their constant care and foresight and perseverance and the able assistance of their staff. Those who have had especially important divisions for the geological problems involved are given due credit in the discussions of part 2, of this bulletin. It is easy, however, to neglect sufficiently full acknowledgment of their services in gathering and formulating data of this kind. Among those having charge of the most important exploratory work the following names should appear:

James F. Sanborn, for sometime assigned to geologic work on the Northern aqueduct.

William E. Swift, in charge of the Hudson river explorations.

William W. Brush, in charge of the early New York city explorations.

Lazarus White, in charge of the Rondout valley explorations.

Lawrence C. Brink, in charge of the Wallkill division explorations.

J. S. Langthorn, in charge of the exploratory work at the Ashokan Reservoir.

Wilson Fitch Smith, in charge of work at Kensico dam, and

A. A. Sproul, in charge of the Peekskill creek and Sprout brook explorations.

Some of these are printed reports and records not directly concerned with this enterprise, but whose information has been found useful in this field. This is especially true of the first four sources enumerated, 1, 2, 3, 4. The last is a specific study with direct reference to this project.

Investigations were begun from the above vantage point. The methods employed and the explorations conducted constituting the further sources of information and furnishing the complete data upon which all conclusions have been based include the following:

- 6 Detailed topographic studies of the engineers of the Board of Water Supply
- 7 Geologic field work making observations in detail of all geologic factors that seem to bear on the problem in hand
- 8 Wash borings for depth to bed rock
- 9 Chop drill holes through stony ground to bed rock
- 10 Shot drill holes in bed rock
- 11 Diamond drill holes
- 12 Test pits and trenches for detail of drift structure
- 13 Test tunnels in rock for working quality
- 14 Deflection tests for holes that have swerved aside
- 15 Pumping tests for underground water supply
- 16 Pressure tests for rock porosity
- 17 Microscopic examinations of rock types
- 18 Laboratory tests of quality and behavior of materials.

The mass of data accumulated from all these sources is surprising. For example, there are upward of 200 wash borings on the different proposed Hudson river crossing lines alone; there are 69 drill borings and 177 wash borings on the site of Kensico dam; there are 69 shot and diamond drill holes on the Rondout siphon line aggregating 10,234 feet of rock core; there are 65 drill holes of various sorts on the Moodna creek siphon aggregating in total penetration of drift over 10,000 feet; there are 106 borings, besides several pits and trenches at Ashokan dam location. At every point explorations suitable to the particular problems in hand were conducted. The whole mass of data is conveniently recorded, much of it is tabulated, some of it is represented graphically, samples of nearly all of the material are available for examination,¹ and all

¹ The cores of all drillings and suitable samples of all borings in drift have been saved and properly labeled and are to be permanently housed at some convenient point on the aqueduct line when completed. At present they are cared for at the different division offices.

have been made use of in coming to a consistent understanding of the conditions.

But the amount of accumulated data is no more remarkable than the difficulties that have been encountered in obtaining it. For example, in the Moodna valley it has taken three to four months' time to put down a single hole to bed rock — the average time consumed for each of the 15 holes exploring the deepest portion of the valley was about 60 days. The chief trouble is caused by heavy bouldery till. In one case a boulder was penetrated for 35 feet, lying a hundred feet above bed rock.

The extreme of such difficulty is, of course, encountered in the Hudson river itself, where the drill has to contend with: (1) the rise and fall of the tides, (2) the river currents, (3) a maximum of 90 feet of water, approximately 700 feet of silt, gravel, till, boulders, etc., filling the old preglacial gorge. The heavy steamboat and towing traffic has been a serious element in the problem. Probably never anywhere have drillmen had to face so nearly insurmountable obstacles. In two years only two holes reached below a depth of 600 feet below sea level. A third, now in progress, has penetrated a depth of 768 feet without entering rock.

CHAPTER III

RELATIVE VALUES OF DIFFERENT SOURCES OF INFORMATION AND STAGES OF DEVELOPMENT

In the earlier stages of work topographic features were of most concern, and they largely controlled the selection of reservoir sites and possible lines for the aqueduct to follow. It was, however, at once recognized that tunnels would be unavoidable and studies as to the types of rock formations to be encountered were begun. It was also early appreciated that the soil or drift cover is very unevenly distributed over the rock surface and that, especially in the chief valleys requiring pressure tunnels, it would be necessary to determine the profile of the rock floor. At this point wash borings were begun. But the natural limitations of the wash rig¹ for penetrating drift of all kinds left the information still too indefinite. The wash rig can not penetrate hard rock. It can not wash up anything but the finer matter, and a boulder of very moderate size is almost as effectual a barrier as true rock ledge. By a combination of washing and chopping or by the use of an explosive to break or dislodge an obstruction some progress in unfavorable material may be made, but the wash rig alone, in a drift-covered region, gives only negative results. It is certain, for example, that bed rock lies at least as deep as the wash rig has penetrated, but it is not certain that it is bed rock instead of some other obstruction. Except in areas of special drift conditions,² therefore, the wash rig was insufficient. To rely upon the process at random was clearly impossible, and to determine whether or not the results of a particular locality

¹ A "wash rig" is a device composed essentially of two iron pipes, one within the other, and so mounted that the inner one can be worked up and down in sort of a churning fashion while water under considerable pressure is forced through it to the bottom and out again by the larger pipe to the surface, carrying up with the current the displaced sand and clay. As progress is made with the inner pipe the outer one is from time to time driven down and the process renewed and repeated till the hole is finished.

² One of the most notable areas of special drift conditions is represented in the Walkhill valley [see discussion in pt 2] where there were developed large deposits of modified drift, stratified gravel, sand and clays, lying immediately upon the bed rock floor. In this the wash bore process was eminently satisfactory, and the rapid progress made by it together with its economy made this an especially attractive method of exploration.

could be relied upon became involved at once with an interpretation of local glacial phenomena, especially an interpretation of the character of the local drift. In order to see the limited application of this method one needs only to point out that the majority of drift deposits in this region are stony or even bouldery, forming thick coverings in the valleys, and to call attention to the experience at two or three points. For example, at Moodna creek, the preliminary wash borings were obstructed and bed rock reported at 5 to 15 feet below the surface where afterward, by other means, it was proven to lie more than 300 feet down. Or again, in the preliminary wash borings in the Hudson, the rigs were stopped and rock bottom provisionally reported at from 25 to 200 feet below sea level, but later explorations have proven at the same point that rock bottom is more than 700 feet down.

Therefore, to the "wash rig" was added the "chop drill" and the "oil-well rig" and to these, or to modifications of them,¹ the success in reaching bed rock has been due.

From independent field studies of a more strictly geologic nature it became clear that many of the valleys, where pressure tunnels were proposed, are of comparatively complex geologic structure and exhibit considerable variety of rock quality and condition. This then introduced and necessitated still more elaborate lines of exploration. It was not enough to know the profile of rock floor alone, it became of equal importance to penetrate the rock and obtain samples of it. So the shot drill² and the diamond drill³ were employed and the drill cores preserved for identification and reference.

¹ The essential features of the machines in most instances are, a high tower or support, a heavy chisel-shaped plunger that can be raised by a rope and dropped repeatedly in the hole, destroying or displacing obstructions, and which can be followed by a casing driven down as progress is made—a combination of washing, chopping and driving.

² The shot drill, or calyx drill, is essentially a machine devised to rotate a steel tube which is so adjusted and manipulated that a supply of small chilled shot can be kept continually under the lower end as it bores into the rock. The cutting is done by the shot immediately under the edge of the tube. A core remains in the tube and may be recovered. Its best position is vertical.

³ The diamond drill consists essentially of a bit or crown set with black diamonds (bort) in such manner that when the bit is attached to a rotating tube a circular groove is cut into the rock. By proper attachment to jointed tubes and driving gear a hole may thus be bored at any angle and to great depth and a core recovered.

These preserved cores, now aggregating many thousands of feet have been of great service in determining the precise limits of formations and consequently the geologic structure or cross section, by which detailed estimates may be guided.

Even these occasionally appeared to give insufficient data. The peculiar behavior of certain holes, as, for example, one or more at Foundry brook,¹ led to the suspicion that the drill had swerved from its course, following a particularly soft seam or zone, and that the results secured by it without large corrections, were wholly misleading. Tests proved that there had been a deflection.

At this and many other places it later became very desirable to form some quantitative as well as qualitative opinion of the conditions existing in the underlying strata. The percentage of core saved, the rate of progress of the drill, the behavior of the drill, the condition of the core recovered, the loss of water in the hole — all these of course were considered.

For more definite evidence as to porosity and perviousness, a series of carefully planned pressure tests² were made. By shutting off connection with the walls of the hole above a certain stratum and forcing water in under pressure, it was possible to demonstrate that certain strata or certain portions were practically impervious in their natural bed, while others were much less so, and to get an idea of their relative efficiency as water carriers. For the pressure tunnels, especially, this test is a very suggestive line of investigation.

¹ At Foundry brook [*see* discussion of this problem in pt 2], the remarkable condition apparently shown was a reasonably substantial ledge of granitic gneiss, 50 feet, followed below by 200 feet of apparently soft sand and reported as such. No core could be recovered. So extensive a zone or bed or layer or mass is hardly conceivable considering the crystalline silicious character of the rock. It probably represents a steeply dipping crush zone along fault movement where the increased underground circulation has been unusually effective in producing decay. After entering this zone the drill swerved from its initial course and kept within the soft seam.

² The pressure test is made by means of a force pump, fitted with a gage on which the pressure is recorded, connected by a pipe to the portion of the hole to be tested, and so adjusted to a device for blockading or damming the hole that the water pressure is confined to those portions of the walls of the hole below the dam, or between two dams if an upper and lower one are used. In this way any portion of a hole, or stratum or several beds together may be tested and the amount of water absorbed per unit of time per unit of pressure determined. This is, of course, directly related to the porosity of the rock and is approximately inversely proportional to its presumed value as an aqueduct carrier.

Where the strata are especially porous and where underground or permanent ground water supplies are very extensive and where at the same time the largest or deepest pressure tunnels are projected some uneasiness has been entertained as to the extent of interference from inflowing water during construction. An attempt to form some idea of the ease of such underground circulation has been made by a systematic pumping of one or two critical holes. The results leave many factors still too obscure to draw definite conclusions. The test will be taken up again in the discussion of the Rondout siphon in part 2.

Laboratory tests and experiments on materials complete the list of lines of investigation with which this bulletin is concerned. Although from the nature of the case these are elaborate and unusually complete, the more important lines are not at all new. All the methods of petrographic, chemical, and physical manipulation that seem to promise practical results of value to the success of the undertaking are followed and the data are organized and interpreted and conclusions are formulated with as great definiteness for practical bearing as other lines of investigation.

CHAPTER IV

GENERAL GEOLOGY OF THE REGION

It will save much repetition and it is believed will altogether serve a useful purpose in maintaining unity of treatment to give an outline of the geologic features of the region in advance of the discussion of special problems. It is intended only for those not sufficiently familiar with the general geology to follow subsequent matters.

The region includes some of the most complicated and obscure sections of New York geology. It is simple in almost no one of the larger branches of the subject. In physiography there is the long and involved history and the results of long continued erosion of a variable series of formations in different stages of modification as to structure and metamorphism and attitude, modified still further by subsidences and elevations, depositions and denudations, peneplanations and rejuvenations, glaciation and recent erosion — all together introducing as much complexity as can well be found in a single area.

In stratigraphy the whole range of the eastern New York geologic column is represented from the oldest known formation up to and including the Middle Devonian — a succession of at least 25 distinct formations which may for convenience be treated in groups that have had similar history. Each of these formations has a constant enough character to map and regard as a physical unit. Even this classification ignores the great range of petrographic variability shown in such formations as the Highlands or Fordham gneisses. All but two or three of these formations will be cut by the tunnels of the aqueduct.

In petrography the range is even greater — so great, in fact, that only an enumeration of the variations will be attempted. They include clastics, metamorphics and igneous types; stratified and unassorted, coarse and fine, detrital and organic, marine and fresh water, homogeneous and heterogeneous, argillaceous, calcareous and silicious sediments, unmodified and thoroughly recrystallized strata; acid and basic and intermediate intrusions; massive and foliated crystallines — of many varieties or variations in each group.

In tectonic geology an equal complexity prevails. There are regular stratifications, cross-beddings, disconformities, overlaps and unconformities; interbeddings, lenses and wedges; flat, warped, tilted

and crumpled strata; monoclinical and isoclinal, open and closed, anticlinal and synclinal, symmetrical and overturned, horizontal and pitching folds; joints, crevices, caves, crush zones, shear zones, and contacts; normal, thrust, dip, strike, large and small faults; veins, segregations, inclusions, dikes, sills, bosses and bysmaliths.

With such variety of natural conditions it is not surprising that the problems of the aqueduct are also of great variety. No two have in all respects the same factors in control and no two can be explored and interpreted upon exactly the same lines.

1 Geographic features or districts. (Physical geography¹)

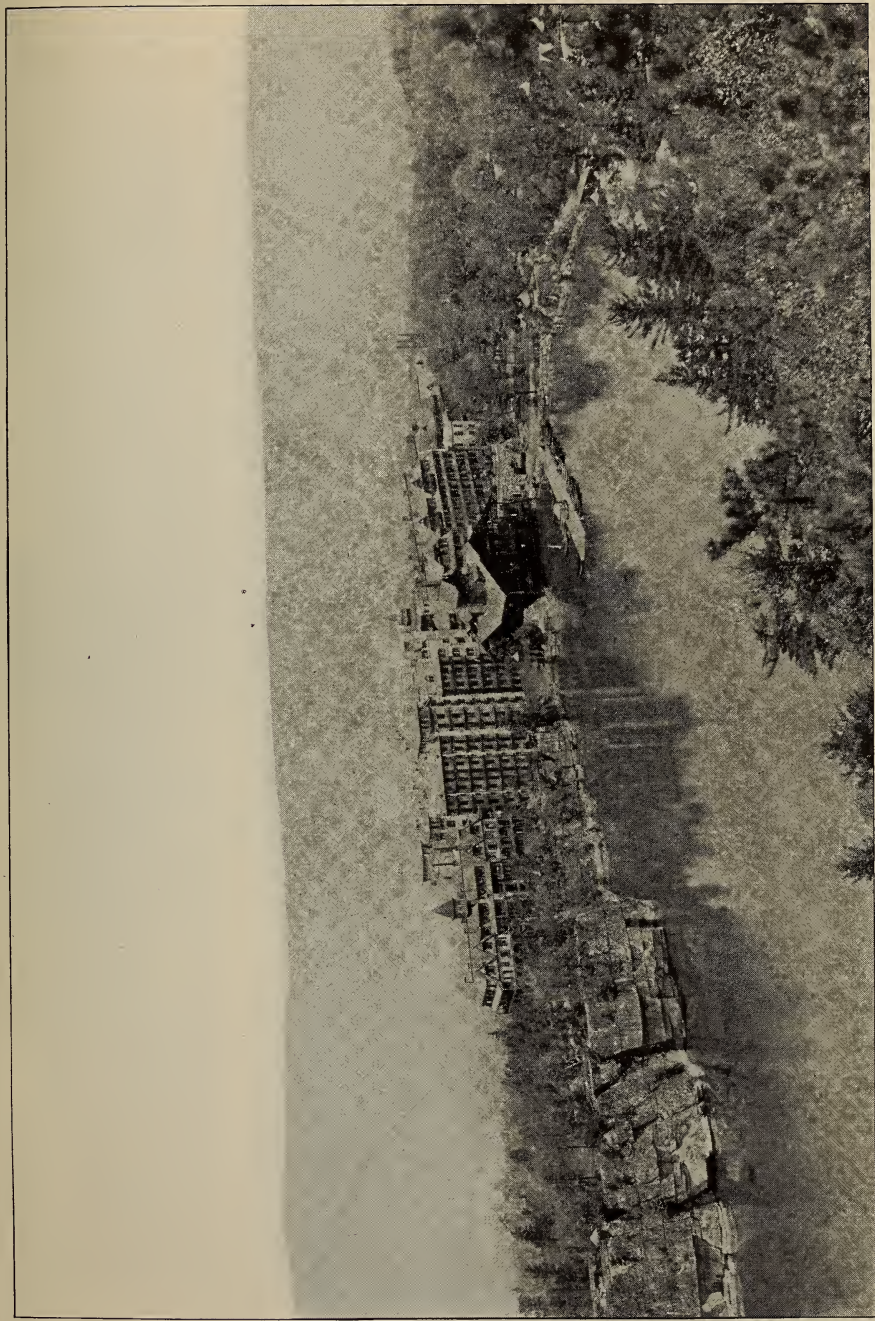
It will be convenient at this point to think of the surface topography by districts — not wholly distinct from each other, but still with essential differences of origin and form. From south to north they are: (a) New York-Westchester county district. The area of crystalline sediments. South of the Highlands. (b) Highlands of the Hudson (Putnam county). (c) Walkkill-Newburgh district. From the Highlands to the Shawangunk range. (d) Shawangunk range and Rondout valley. (e) Southern Catskills.

All have been sculptured by the same forces and with similar vicissitudes, but the difference of history and structure and condition, already established when the physiographic forces began on the work now seen, have caused the variety of surface features indicated in the divisions made above. The more noticeable characteristics of these five districts are here given.

a New York-Westchester district. The area south of the Highlands proper is characterized by a comparatively regular succession of nearly parallel ridges separated by valleys of nearly equal extent ($\frac{1}{2}$ to 5 miles wide), making a surface of gently fluted aspect and of moderate relief (0-500 feet) sloping endwise toward the Hudson and the sea. The controlling factors in producing this topography are involved in a series of folded, foliated, crystalline sediments, of differing resistance to destructive agencies.

b The Highland region is one of rugged features, with a range of elevation of 0-1600 feet A. T., forming mountain masses and ridges separated by very narrow valleys all having a general northeast and southwest trend across which the Hudson cuts its way in a narrow, angular gorge, forming the most constricted and crooked portion of its lower course. The bed rock is all crystalline,

¹The physiographic history of a region is not understandable without a comprehensive knowledge of its geologic features and structures and history. It is therefore treated in a later paragraph.



View looking west from Sky Top in the Shawangunk range with Mohonk lake in the foreground and the Rondout valley in the distance with the Catskills in the background. (Photograph by the Board of Water Supply)

of massive and foliated types, metamorphosed sediments in part with large masses of igneous intrusions and bosses.

c **The Walkill-Newburgh district** lying immediately north of the Highlands and extending to the Shawangunk range is a region of gently rolling contour. Most of the area along the proposed lines lies between 200 and 500 feet above the sea. There are only occasional rugged hills or short ridges, such as Snake hill and Skunnemunk. The valleys are broad and smooth and the divides are simply broad, hilly uplands. Bed rock is chiefly Hudson River slates with occasional belts of Wappinger limestone. The larger features, the trend of divides and valleys, are northeast and southwest, although this regularity is not so marked as in the preceding two districts. But the chief streams flow either northeast or southwest to the Hudson along these general lines.

d **The Shawangunk range and Rondout valley** form a transitional unit from the complicated structural and tectonic conditions of the southerly districts to the uniform and almost undisturbed strata of the Catskills. Its southeasterly half is a mountain ridge partaking of extensive faulting and folding and represented by the Hudson River slates overlain unconformably by the thick and very resistant Shawangunk conglomerate forming high eastward-facing cliffs. Toward the northwest these disturbances diminish, the strata gradually pass deeper beneath a great succession of shales, limestones, and sandstones of the Helderbergian series, and a broad valley is eroded in the softer portions. It is limited on the northwest by the prominent and very persistent escarpment bordering the Hamilton series and forming the outer margin of the Catskill mountains.

e **The Catskill area** is of simple structure. The strata are well bedded and lie almost flat with a gentle dip northwest. The surface features form a series of irregularly distributed escarpments, hills, valleys, cliffs, gorges and mountains, rising rapidly toward the west, with moderate to strong relief and reaching elevations of 2500 feet. The failure of the northeast-southwest trend of feature that is so common in all of the other districts is a marked difference. It is directly due to the flatness of the strata.

2 Stratigraphy

There are no strata of prominence in association with the main aqueduct younger than Devonian age except the glacial drift. Immediately adjacent areas, however, some of which are covered by the accompanying maps, and Long Island have later formations ex-

tensively developed. Such are the Triassic rocks of the New Jersey side of the Hudson below the Highlands, and the Cretaceous and Tertiary strata of the Atlantic margin on Long Island and Staten Island. The development of underground water supply on Long Island is especially concerned with these later formations, and with the modified drift deposits of the continental margin.

The whole series of formations are more commonly considered in groups that exhibit certain age or physical unity and that are for the most part characteristic of certain regional belts and that coincide somewhat roughly with the physiographic divisions already noted. There is in the following description and tabulation no direct attempt to unduly emphasize this relation or to belittle the divisions recognized in the commonly adopted geologic column. It is, however, for the purpose in hand, more convenient and useful to keep clear the physical groupings, because largely these groups, instead of the more arbitrary subdivisions of age, are the units used in considering structural and applied problems.

a Quaternary deposits. (1) *Glacial drift.* A loose mantle of soil and mixed rock matter covers the bed rock throughout the whole region except (*a*) here and there where the rock sticks up through (outcrops), and (*b*) at the most southerly margin along the coast where the glaciers seem not to have reached.

Origin. This mantle is usually very different in lithologic character from the underlying rock floor. There is almost always an abrupt break between the rock floor and the overlying material. The rock floor is grooved, smoothed, and scratched as if by the moving of rock or gravel over it. The larger boulders are usually of types of rock identical with ledges lying northward at greater or less distance. Materials of exceedingly great variety both in size and condition and lithologic character are often all piled together in the most hopelessly heterogeneous manner. These are now commonly regarded as conclusive evidence of glacial origin. There is no need of making the discussion exhaustive. It is almost universally called the "*drift.*"

Thickness. The thickness of the drift varies from almost 0 to approximately 500 feet. It is generally thickest in the valleys where it has simply filled many of the original depressions and obliterated much of the ruggedness of surface, the gorges and ravines and canyons of the preglacial time.

Sources. It appears from an examination of the grooves and striae on bed rock, and the relationship of the different types of drift to each other, and from a comparison of the types of boulders

with the ledges that may be regarded as their source, that the general ice movement was from north to south swerving along the southerly extension to east of south. Therefore it is not unusual to find abundant boulders of Palisade trap stranded in New York city or on Long Island, or boulders of the Cortlandt series, or of the gneisses of the Highlands, or, in occasional instances, of sand stones from the Catskills, or the limestones from the Helderbergs or perhaps in rarer cases even rocks from greater distance, as the Adirondack mountains.

Kinds of drift. There are in the region two fundamentally different types of drift as to method of deposition. They are (*a*) unsorted drift (till or hardpan), and (*b*) modified drift (stratified or partially assorted gravels, sands, clay, etc.). The former (*a*) represents deposition directly from the ice sheet at its margin (terminal or marginal moraines) or beneath ("ground moraine") without enough water action to rework and assort the material. It therefore contains boulders, pebbles, sand and clay of a heterogeneous mixture of the most complex sort both as to size and character. In such deposits there is almost always sufficient intermixture of clay and rock flour of the finest sort to make a very compact and dense mass that is usually quite impervious to water. Such deposits are distributed rather unevenly over the surface and where this unevenness leaves hollows or basins, or obstructs the outlets of other depressions, they may hold water and form small lakes or ponds or swamps. This is almost universally the origin of the many thousands of lakes of the northern lake region. It is evident that material of this character, a type that commonly serves the purpose of a natural dam or reservoir, would be especially important and useful at certain places on the Catskill system. As a matter of fact, so far as geologic features are concerned, it is the chief factor in choice of location for the Ashokan dam [*see* discussion pt 2] and is a controlling factor in the plans for the erection of the miles of dikes at less critical margins of the reservoirs. Till is an extensively developed type but frequently passes abruptly either laterally or vertically into assorted materials of very different physical character.

(*b*) All materials associated in origin with the glacial occupation that have been materially modified especially in the direction of an assorting of material are referred to as "modified drift" deposits. They include (1) deposits made by both water and ice together, (2) those formed by running water, (3) those laid down in stand-

ing water. Or again (1) those accumulated rapidly with very irregular supply of material at the margin of the ice-forming, hummocky or hill and kettle surface (kames, eskers), (2) those carried along valleys or general lines of drainage to a considerable distance beyond the ice margin aggrading the valley with the overload of gravels and sands (valley trains), (3) those washed out from the ice margin in more even distribution forming a gently sloping and thinning extramarginal fringe (outwash or apron plains), (4) those fine matters that are carried by glacial streams into the margins of more quiet waters, either a temporary or a permanent lake or a larger and slower stream or other body forming more perfectly assorted and more evenly stratified deposits (delta deposits), (5) those finer rock flours and clays that remain suspended longer and carry out much farther settling only in the very quiet waters of lakes or estuaries or temporary water bodies of this character forming the perfectly banded clays (glacial lacustrine clays).

It is evident then that modified drift has in the process of its accumulation suffered chiefly a separation of fine from the coarse particles and that in most cases the fine clay filling that makes the till dense and impervious to water, has been washed out and deposited by itself in the more inaccessible deeper waters. As a result most modified drift deposits are pervious and easy water conductors, but poor or questionable ground for dikes or dams or basins [see discussion of Ashokan dam, pt 2].

Some of them, the medium sands and gravels, furnish an excellent and already cleaned structural material for concrete or mortar, such as the Horton sand deposit, or coarser kinds may be crushed and sized before using as is done at Jones Point on the Hudson.

The finer silts and clays, usually overlain by assorted sands, are abundant along the Hudson, having been deposited there at a time when the water of this estuary stood 50 to 150 feet higher than now. Recent erosive activity of the river has cut the greater proportion of the original deposits away but at many places large quantities still remain above water level in the banks and still greater quantities extend beneath the river. These deposits are the support of the brick industry of southeastern New York. The till deposits are very difficult to penetrate in making borings because of the boulders, the wash rig being almost useless. Modified drift of the medium and finer sorts is easily and cheaply penetrated, and, if it lies on bed rock, such exploration gives reliable results.

Structure. But this is stating the actual conditions too simply. The glacial epoch was a complex one. The continental ice sheet may

have advanced and retreated repeatedly, how many times in this region is not clear. With each time of advance and retreat, the work done by it partly destroyed, or disturbed or modified or covered the earlier ones in what appears now to be a most arbitrary way (in reality, of course, in a very consistent way for the conditions that then existed). So one frequently finds a till beneath a deposit of stratified drift, or modified drift beneath till, or a succession of a still greater number of changes in almost hopeless confusion. In New York city, for example, at Manhattanville cross valley, the exposed drift above street level includes (*a*) at the bottom, water-marked stony till and assorted gravels, (*b*) in the middle perfectly horizontal, stratified rock flour and the finest sand, (*c*) top, wholly unsorted bouldery till, covered by thin soil. It is evident that the most careful and accurate identification of the surface type without subsurface investigation would give, for such uses as are now being considered, thoroughly unreliable evidence as to the behavior of the whole body at this point. Therefore, a determination of the changes and quality forms an essential record. All of these types are to be found in the region, but the different grades of till and roughly modified material belonging to the same type are more common inland.

On Long Island the development of marginal modified types is extensive and more or less obscured by the advance and retreat noted above. The larger divisions recognized in deposits are (*a*) an early accumulation of sands and gravels, strongly developed near the western end of the island, known as the "Jameco" gravel, (*b*) an interglacial (retreatal) deposit of blue clays known as the "Sankaty" beds, (*c*) a later series of deposits, sands, clays, gravels and till, belonging to the closing stages of the ice period corresponding to the surface deposits of the larger portion of the whole region (Tisbury and Wisconsin advances). Some of these sands and gravels are important water-bearing sources for the new Brooklyn additional supply.

The whole Long Island series according to Veatch¹ includes:

Wisconsin stage	{ Glacial two lines of ter- minal moraines with out- wash plains }	} Harbor hill moraine } Ronkonkoma moraine
Tisbury stage		

¹ After PP 44, U. S. Geological Survey, p. 33.

Gay Head	}	Folding (glacial folding)
		Sankaty retreatal stage (interglacial) clay beds
Jameco	}	Glacial — Jameco gravels
		Postmannelto erosion (interglacial)
Mannelto stage		Glacial — old gravels

A radically different and in some respects a much simpler interpretation¹ of the Long Island deposits has been outlined by W. O. Crosby. The essential feature of his classification is the unity and simplicity of the glacial epoch. Only the moraines and associated sands and gravels of outwash origin during advance and retreat are regarded as glacial. All other deposits below and including the Sankaty clay beds he regards as preglacial.

The Jameco gravels are interpreted as Miocene in age.

Certain persistent yellow gravels overlying the Jameco are classified as Pliocene.

b Tertiary and Cretaceous deposits. (2) *Tertiary outliers.* Deposits of *Pliocene* age are littoral in type [PP 44 U. S. G. S. p. 28] and are not very well differentiated (Long Island, Staten Island). Probably equivalent to the *Bridgeton* beds of New Jersey.

Certain "fluffy" sands in thin beds are assigned by Mr Veatch to the *Miocene* (Long Island, Staten Island). Probably equivalent to the *Beacon hill* deposits of New Jersey. Crosby places the Jameco gravels in the Miocene together with the Kirkwood lignitic and pyritic clays and sands.

(3) *Upper Cretaceous* deposit² are extensively developed. They form the chief bed rock of Long Island.

¹ The writer offers both of these outlines of the glacial and associated deposits in preference to either alone. Both Veatch and Crosby have given immensely more time to the study of these questions than any one else. It is hardly fitting for a newcomer in their field to reject either view. But because of the very great difference between the two interpretations one may be pardoned a preference. It is the writer's opinion that the simpler outline is the more tenable. It does not seem possible to establish a very complex series of stages in the glacial epoch as represented in the deposits of southeastern New York.

² Crosby's classification of the Cretaceous is as follows:

- (a) Monmouth — slight development of marls. (Lower and middle marl series.)
- (b) Matawan — (clay marl series) probably present on Long Island.
- (c) Magothy — an extensive series of variegated and micaceous sands and clays. Heavy development on Long Island.
- (d) Raritan — Plastic clay scales and the Lloyd sand.

(a) A ligniferous sand with occasional clay beds forming the *uppermost* of the *Cretaceous* series is probably equivalent to the *marl* series of New Jersey. But it lacks the prominent greens and development characteristic of the region further south. Not clearly separable from the underlying formation or Matawan beds.

(b) The Matawan beds. Gray sands and clays.

(c) Raritan formation. Clays and sands, plastic clays, the *Lloyd sand*, an important water carrier lies about 200 feet below the top of the formation. Occasional leaf impressions.

All of these formations, except where disturbed locally by glacial ice, dip gently seaward. The sand beds of these strata are the chief sources of underground water being developed by the new system.

c **Jura-Trias formations.** (4) *Palisade diabase*. This is a thick intrusive sheet, or sill, of igneous rock of diabasic type. It is 700-1000 feet thick. It lies for the most part parallel to the bedding of the surrounding, inclosing, sedimentary rocks, and, rising gently eastward, forms a strong cliff continuously along the west bank of the Hudson for 40 miles. It varies from very fine to very coarse texture and is for the most part fresh, tough, durable, and is the source of large quantities of the most satisfactory quality of crushed stone now on the market for use in concrete.

(5) *Newark series*. This is a very great thickness of silicious sediments, chiefly reddish conglomerates, red and brown quartzose and feldspathic sandstones and shales. They dip gently westward and northwestward at 10-20 degrees, and are confined, in this region, to the west side of the Hudson south of the Highlands. The formation supplies "brownstone" for building purposes.

None of the Jura-Trias rocks, so far as known, will be cut by the aqueduct.

d **Devonic strata.** (6) *Catskill formation*. This formation¹ is of continental type, chiefly a conglomerate. A white conglomeratic sandstone forming the uppermost portion attains its greatest thickness on Slide mountain (350 feet). It is a "coarse grained, heavy bedded, moderately hard sandstone containing disseminated pebbles of quartz or light colored quartzite, and streaks of conglomerate."

A red conglomeratic sandstone constitutes the much thicker portion below (1375 feet). It is a "coarse, heavy bedded sandstone of dull brownish hue containing disseminated pebbles and conglomeratic streaks, differing from the overlying beds chiefly in color. In

¹ Grabau, A. W. N. Y. State Mus. Bul. 92. Geology and Paleontology of the Schoharie Valley.

both series the pebbles and conglomeratic streaks are scattered and irregular, while the sands are often cross-bedded. Thin layers of red shale occur, and locally gray sandstones." The deposits probably represent flood plains, deltas, and alluvial fans accumulated mostly above sea level.

(7) *Oneonta sandstone* (Upper flagstone). "Thin and thick bedded sandstones from 20 to 200 feet thick with interbedded red shales up to 30 feet thick." Chiefly light gray to brown in color. Abundant cross-bedding, occasional dark shale, frequent flagstone beds. Capable of furnishing "bluestone" flags and more massive dimension stone. To be seen in the vicinity of West Shokan and westward.

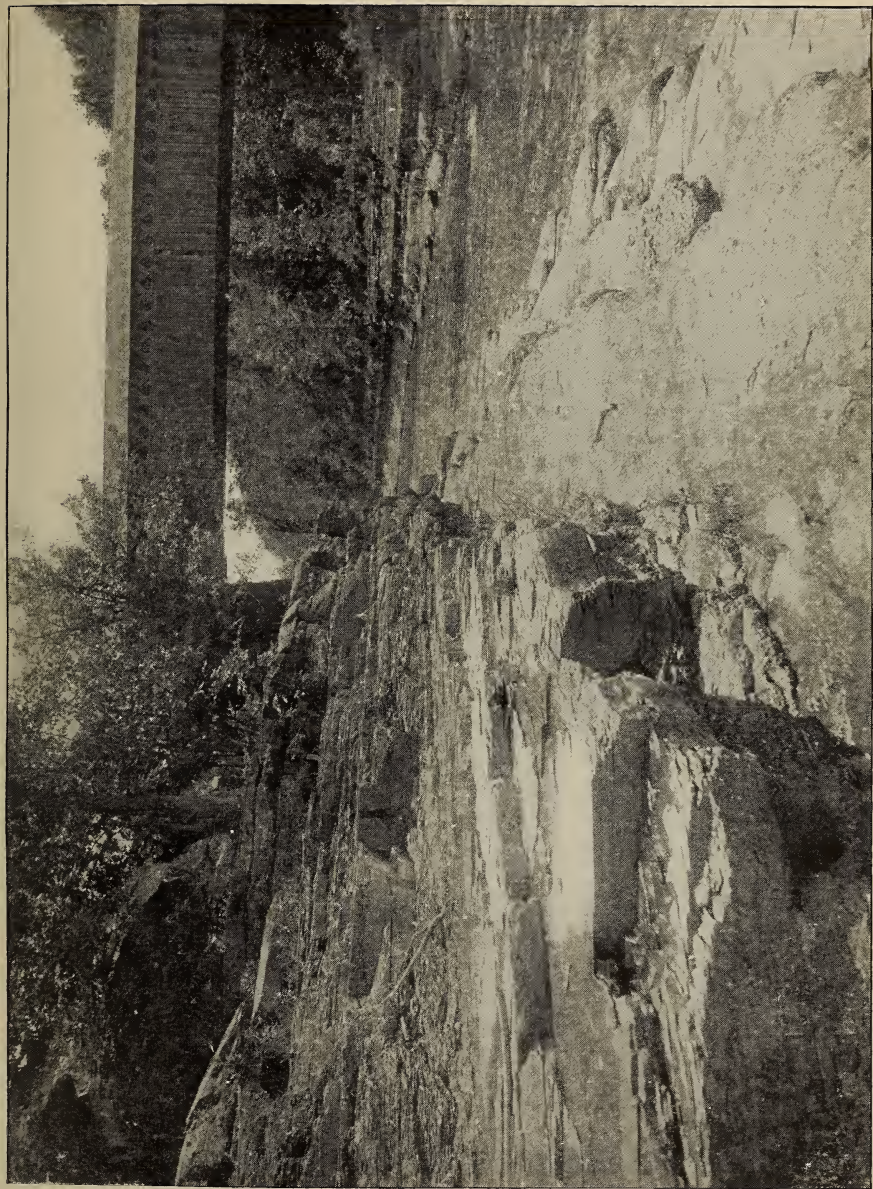
(8) *Ithaca and Sherburne* (lower flagstone "bluestone"). "Thin bedded sandstone, with intercalated beds of dark shale. The sandstones are in masses from a few inches to 40 feet in thickness, greenish gray to light bluish gray or dark gray in color, and are extensively quarried as flagstones." There are occasional conglomeratic streaks. Occurs in large development in the vicinity of the Ashokan reservoir (500 feet). The heavier cross-bedded and coarser grained beds are capable of furnishing an unusually good quality of large dimension stone for heavy structural uses. The beds of this formation near Olive Bridge will in all probability furnish the greater proportion of stone of all kinds for the construction of the great Ashokan dam [*see* discussion of bluestone near Ashokan dam, pt 2]. The chief common fossil content is impressions of plant remains.

(9) *Hamilton and Marcellus shales*. "Dark gray to black or brown shales with thin arenaceous beds in the upper part." Forms the upper portion of the escarpment that follows the outer margin of the Catskill foothills bordering the westerly side of the middle Rondout and lower Esopus valleys. Occasionally beds are substantial enough for flagstone production (700 feet or more with the Marcellus.)

The chief index fossils are: *Spirifer mucronatus*, *Athyris spiriferoides*, *Chonetes coronatus*.

The Marcellus shale is not readily differentiated in the Esopus valley. Characteristically it is a thin bedded shale of no great thickness (180 feet in the Schoharie valley) lying between the Onondaga limestone and the Hamilton and obscured by talus from the escarpment (with the Hamilton 700 feet.)

Styliolina fissurella, *Chonetes mucronatus*, *Strophalosia truncata*, *Liorhynchus mysia*.



The Sherburne flags at Olive Bridge. (Photograph by Board of Water Supply)

The dividing lines between the different sandstones and shale formations, the Oneonta, Ithaca, Sherburne, Hamilton and Marcellus, can not be sharply drawn in the Esopus region. Together they form in a large way a rather satisfactory field unit. For specific purposes it is necessary to recognize that the lower portions are prevailing shales with thin bedded sandstones while the upper portions are much more heavily bedded, the sandstones pre-

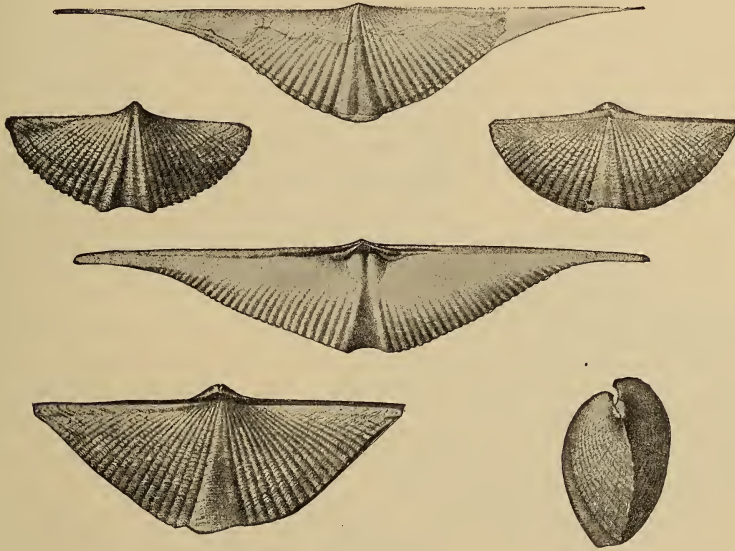


Fig. 2 *Spirifer mucronatus* (Conrad), a characteristic and abundant index fossil of the Hamilton shales of the Catskill margin

vailing. The five divisions may possibly be more satisfactorily made on paleontologic characters than on physical, but in most of the advisory reports on economic and practical problems involving this district the subdivisions can not be emphasized. The whole series is essentially conformable and is very little disturbed [*see* report on bluestone quarries, pt 2].

(10) *Onondaga limestone*. A bluish gray, massive, thick bedded cherty, somewhat crystalline limestone. It is strongly marked off from the Hamilton and Marcellus above, and, because of its greater resistance to erosion, usually forms a dip slope controlling stream adjustment and ultimately inducing the development of unsymmetrical valleys with gentle easterly slopes and clifflike westerly borders where the streams are sapping the overlying Marcellus and Hamilton shales. It is not sharply separable from the Esopus below but everywhere in this region graduates into it with increase of silicious

and argillaceous impurities. Estimating the formation from the drill cores that have penetrated it, and placing the lower limit as nearly as may be at the horizon of changes from predominant lime to predominant silicious content, the approximate thickness in this region is placed at 200 feet. The rock where exposed exhibits considerable joint development and these are considerably enlarged by the solvent action of percolating waters. This factor is considered of some importance in connection with the other limestones of the district in aqueduct construction and permanence. The Onondaga has been used as a building stone formerly sold as marble, some grades of which are good stone. On the line of the aqueduct it is confined to the Rondout and Esopus valleys. The chief fossils are: *Atrypa reticularis*, *Zaphrentis prolifica*, *Leptostrophia perplana*, *Platyceras dumosum*, *Leptaena rhomboidalis*, *Dalmanites selenurus*.

(11) *Esopus and Schoharie shales* (a slaty grit). The Schoharie as a distinct formation is not distinguishable in this region. The very thick and comparatively uniform, gritty, black, dense, almost structureless rock is a distinct unit. It is a silicious mud rock with very obscure sedimentation markings, but showing independent secondary cleavages induced by later dynamic factors, and, on long exposed surfaces always exhibiting chiplike fragments as the result of weathering. But it is not an easily destroyed rock. In so far as the bedding is obscure and the induced structure predominates, the rock is a slate; and in so far as it is distinctly gritty (sandy) instead of argillaceous it is a grit. The formation might therefore be more accurately designated as a slaty grit. The lack of plain bedding structure makes it impossible to estimate its thickness, since the foldings or other displacements can not be allowed for; but the accumulated data of drill holes in more advantageous position indicate an approximate thickness of 800 feet. The rock is considered exceptionally good ground for the tunnel.

A few fossils occur the most characteristic being *Taonurus caudagalli*. There are also in certain layers of limited extent, *Leptocoelia acutiplicata* and *Atrypa spinosa*.

(12) *Oriskany and Port Ewen transition* (silicious shaly limestone). There is no well defined and distinct separation here between the Oriskany and the underlying Port Ewen, but because of the importance and persistence of the formation in other and related areas the name is held. The equivalent of the Oriskany is in this district involved with a strongly developed transition zone which in physical features is intimately associated with the Port

Ewen as a single unit. If any distinct formation is to be recognized it would be on the basis of transitional faunal character, placing the fossiliferous upper 100 feet in the Oriskany transition and confining the name Port Ewen to the rather unfossiliferous and concretionary, shaly, argillaceous limestone of the lower 100 feet.

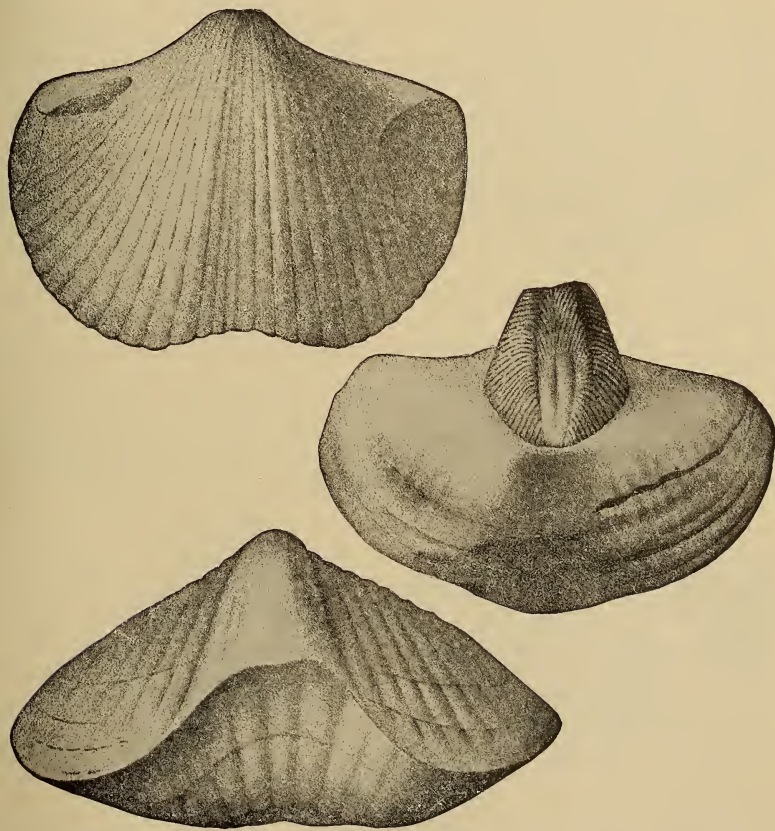


Fig. 3 *Spirifer arenosus* (Conrad), one of the characteristic index fossils of the Oriskany occurring in the Port Ewen-Oriskany transition

This transition rock is strongly bedded, argillaceous and silicious limestone, very quartzose in certain layers, but there are no exposures in this area that would be called sandstones. Fossils are abundant and show marked Oriskany peculiarities. Those of most characteristic relations are: *Hipparionyx proximus*, *Leptostrophia magna*, *Spirifer murchisoni*, *Spirifer arenosus*, *Platyceras nodosum*, *Strophostylus expansus*.

(13) *Port Ewen shaly limestone*. The beds below those noted in the preceding paragraph are essentially argillaceous, shaly limestones. They vary from rather massive to thin bedded, are dark grayish in color, and have a peculiar nodular or concretionary development along certain sedimentation lines. These spots have less resistance to weather than the surrounding rock and therefore develop rows of pits along the face of an outcrop. Their size, 6 to 18 inches or more across, together with their persistence makes an easily recognized physical feature. The few fossils that are found are not very characteristic. The following should be mentioned: *Spirifer perlamellosus*.

In the discussion and on the maps the Port Ewen and Oriskany are treated together as a single unit as the Oriskany-Port Ewen beds.

(14) *Becraft limestone*. Massive, heavy to thin bedded, light colored, semicrystalline to thoroughly crystalline limestone. More massive beds very pure, 94+ % CaCO_3 . Shaly beds resemble the



Fig. 4 *Sieberella pseudogaleata* Hall, the most characteristic index fossil of the Becraft limestone of the Rondout region

New Scotland which they pass into at the base. The most characteristic features for field identification are (a) pink or light colored spots, (b) a more coarsely crystalline condition than any of the associated strata, (c) occasional large calcite cleavages to be seen wherever a fossil crinoid base *Aspidocrinus scutelliformis* is broken, (d) the very characteristic fossil *Sieberella*

pseudogaleata, and (e) many crinoid stems.

The formation carries many fossils in addition to those given above, among which are *Spirifer concinnus*, *Uncinulus campbellanus*.

(15) *New Scotland shaly limestone*. Thin bedded, dark gray to reddish sandy and shaly limestones. The rock breaks out in slabs on weathering and develops red iron stains. It has especially abundant fossils, the most characteristic of which are: *Orthothes woolworthanus*, *Spirifer macropleura*. Other common ones are: *Leptaena rhomboidalis*, *Strophonella headleyana*, *Ripidomella oblata*, *Stropheodonta becki*.

(16) *Coeymans limestone*. Heavy bedded, dark gray, argillaceous and flinty limestone. The characteristic features for field identification are (a) abundant chert nodules, (b) the occurrence of coral reef structure and heads of corals, *Favosites helder-*

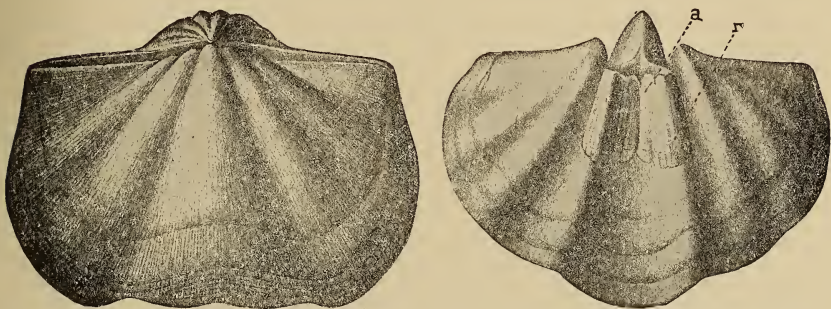


Fig. 5 *Spirifer macropleurta* (Conrad), the most characteristic index fossil of the New Scotland beds in the Rondout region

bergia. The brachiopods *Sieberella galeata* and *Atrypa reticularis* are very common.

This formation has a thickness of about 80 feet and is rather distinctly separated from the underlying Manlius. The Coeymans is considered the base of the Devonian system of New York. It is

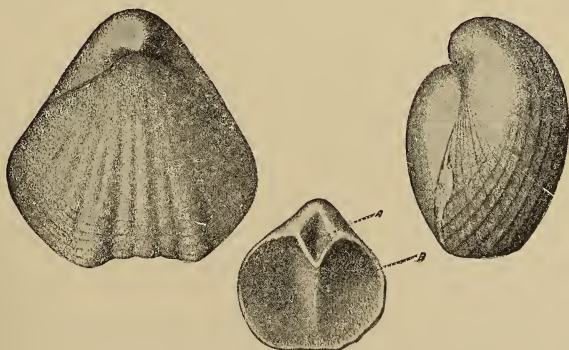


Fig. 6 *Sieberella galeata* (Dalman), the most reliable index fossil of the Coeymans limestone of the Rondout region

perfectly conformable upon the underlying series and it is evident that in this region there was no important break in the progress of deposition.

e Siluric strata. (17) *Manlius limestone*. Lime mud rock, fine textured, dense, with plainly marked sedimentation lines, gray to dark gray color. The most characteristic features in the field are (a) fine texture, (b) sedimentation lines, as if laid down in quiet waters as a lime mud, (c) solution joints sometimes enlarged to

cavelike form into which surface streams disappear (such as Pompey's cave near High Falls), (d) mud crack surfaces (in lower beds), (e) occurrence of the fossil *Leperditia alta*.

Its abundant jointing and the tendency to develop solution cavities from them is considered an objectionable character.

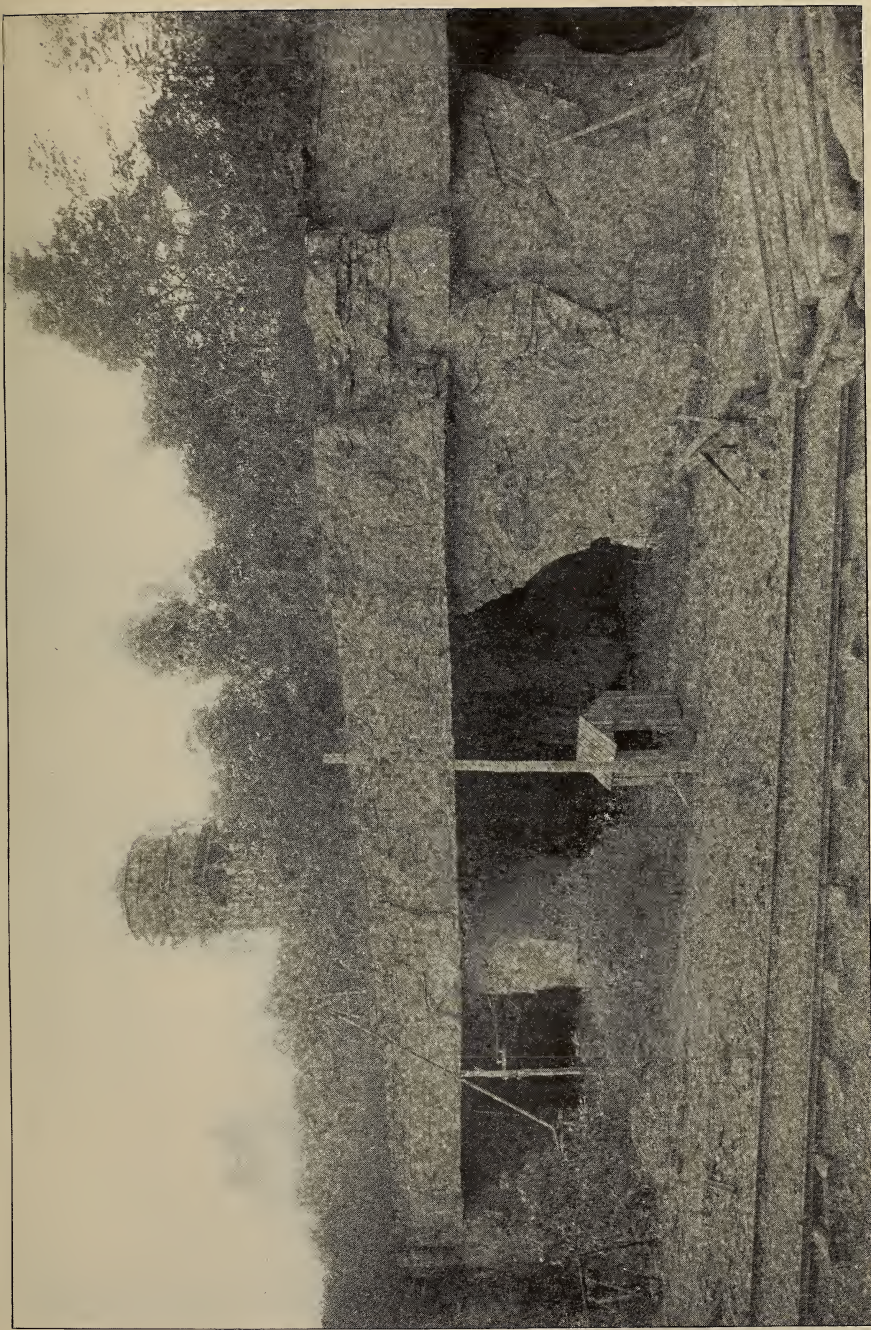
(18) *Cobleskill and cement beds* (limestone). It is not possible without the most painstaking, comparative, chemical and paleontologic research to differentiate the cement layers from the inclosing beds and to assign them all to the subdivisions that are recognized in some previous publications,¹ as the (a) *Rondout* cement (b) *Cobleskill* limestone, (c) *Rosendale* cement, and (d) *Wilbur* limestone. There are, however, two workable natudal cement beds, both at Rondout and at Rosendale, with a nonworkable layer between each case, and also one between the lower and the next underlying formation. Whether the two cement beds at Rondout represent the *Rondout* and the *Rosendale* horizons with the *Cobleskill* between, or whether they should both be regarded as *Rondout* with *Cobleskill* below, can not concern our present problems. And again, whether or not the two cement beds at Rondout are the same two that appear at Rosendale, or whether they are equivalent only to the upper one with a new lower bed (The *Rosendale*) added in this area and then with the *Cobleskill* between these two as claimed by Grabau, does not alter the plain fact that the whole series is a physical unit. It is a gray, rather close texture limestone, resembling the *Manlius* proper, and contains few fossils. It is perhaps even better yet to group all of these limestone beds below the *Coeymans* into a single unit and call it the *Manlius* series.

(19) *Binnewater sandstone*. Below the *Manlius* cement rock series lies the 60-100 foot *Binnewater*. It is chiefly a well bedded quartz sandstone, almost a quartzite in the upper beds with more shale in its lower portion, in color varying from white to greenish yellow and brown. The rock is rather porous in certain beds and especially along the bedding planes and is not well recemented where crushed by crustal movements. It is confined to the *Rondout* valley.

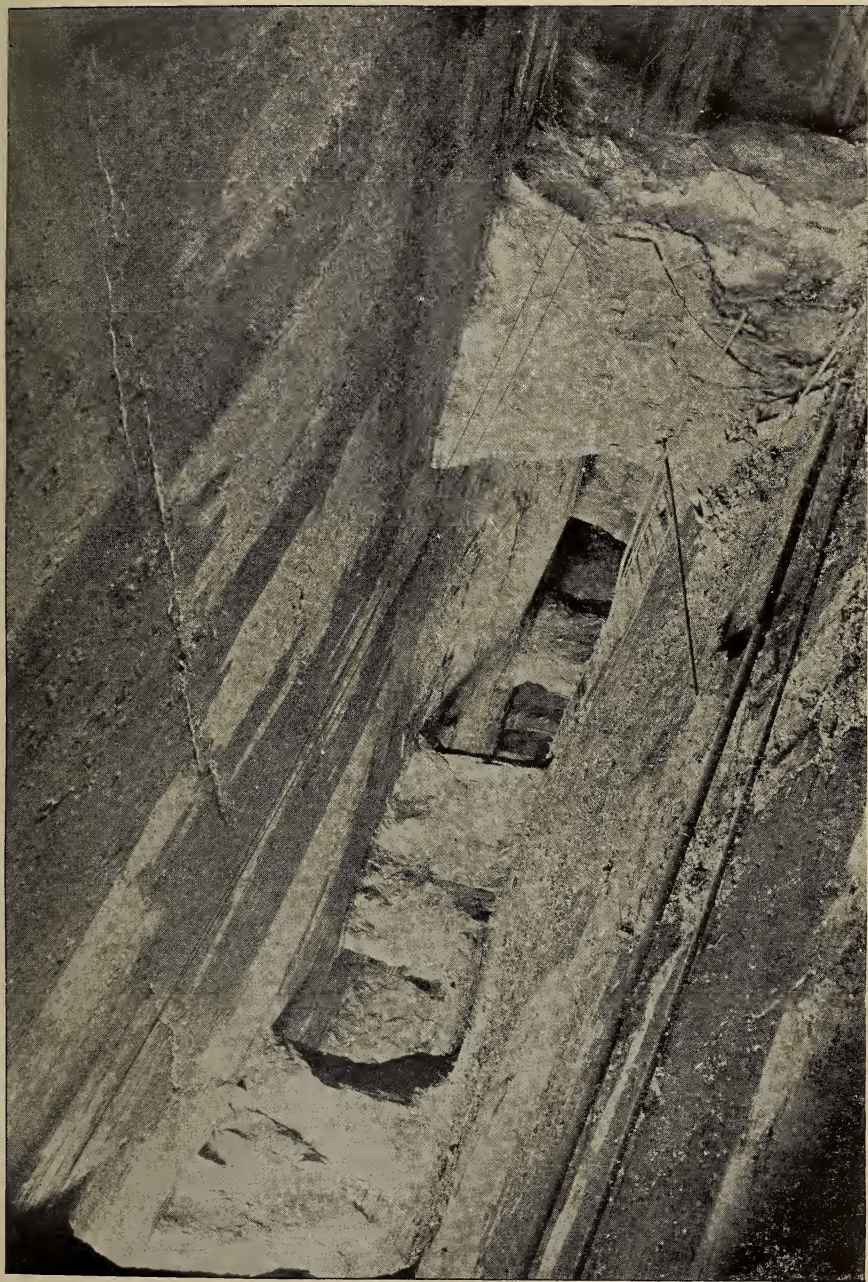
(20) *High Falls shale*.² Greenish to red argillaceous to sandy shales. The exposures are often a brilliant red while the rock

¹ N. Y. State Mus. Bul. 92 (Grabau), p. 311-13; N. Y. State Mus. Bul. 80 (Hartnagel), p. 355-58; N. Y. State Mus. Bul. 69 (Van Ingen and Clark), p. 1184, 1185.

² The term given by Hartnagel. N. Y. State Mus. Bul. 80. p. 345.



Limestone beds of the Rosendale cement region. The Beach mine near Rosendale. (Photograph by T. C. Brown for the Board of Water Supply)



Interior of the Norton cement mine, Binnewater, N. Y., showing the thickness and dip of one of the cement beds and the method of mining. (Photograph by T. C. Brown for the Board of Water Supply)

from drill cores is seldom highly colored. The protected beds are more commonly greenish in color and contain much iron sulphide. Occasional thin limestone beds occur in the upper portion at High falls — one of 4 feet forms the lip of the lower fall. The High Falls shale is confined to the Rondout valley and on the line of the aqueduct is 67–100 feet thick.

(21) *Shawangunk conglomerate*. The Shawangunk is a conglomerate and sandstone. The constituent pebbles are almost wholly quartz, well worn, and varying in size from that of sand to pebbles of several inches diameter. But for the most part the pebbles are small, abundantly mixed with sand, bound together by a silicious cement. Rarely a true quartzite is developed and still more rarely a shaly facies. The rock is therefore very hard, brittle, and in the undisturbed portions fairly impervious and resistant. But it suffers from crushing along zones of disturbance in folding and faulting and these zones are very imperfectly recemented. It is a durable rock, very resistant to ordinary decay, but forms great talus slopes. It is used for buhrstones (millstones), etc. It varies in thickness on the lines of the aqueduct from 280–400 feet. The rock is limited in its northward extension to this district — southwestward it is much more broadly exposed in the continuation of the Shawangunk range.

The Shawangunk completes the conformable Siluro-Devonic series down to the erosion interval at the close of the Ordovician. The series of conglomerates, sandstones, limestones, and shales make an imposing column approximating 3000 feet of strata differentiated with more or less ease into 15 separate and mappable formations and a possible 5 or 6 more with careful paleontologic work. The series begins with the capping beds of the Shawangunk range and its northward extension toward the Hudson river at Rondout and Kingston, and thence westward constitutes the rock floor while its structures control the surface configurations far beyond the limits of the region under consideration. Immediately to the north and partly within the area here treated is the famous Rosendale cement region, the pioneer cement district of America and for many years the best producer. The strata used are almost exclusively the upper members of the Siluric ("cement beds") closely associated with the Cobleskill between the Manlius proper and the Binnewater sandstone. Rarely the Becraft from the Devonian series furnishes some cement rock.

f **Cambro-Ordovician formations.** Between the Precambrian metamorphics of the Highlands beneath and the Siluro-Devonic

sediments of the Shawangunk range and the Catskills above, lies a series of quartzites, limestones and slates less complexly disturbed than the older and more disturbed than the younger series — set off from both by unconformities representing time intervals that cover both folding and erosion. They are of more than 4000 feet thickness — how much more it is impossible to estimate because of the obscurity of data in the slates. There are very few fossil forms preserved in them. The series is, however, readily and sharply separable into three formations that may be mapped upon lithologic characters alone. They are of most importance in the Wallkill valley, Moodna creek, Newburgh, Fishkill, New Hamburg and Poughkeepsie districts. Their character, structure, and conditions have required careful consideration in the decisions on the Wallkill and Moodna siphons and in the discussions on the proposed Hudson river crossings [*see* Hudson river crossings, pt 2].

(22) *Hudson River slates.* The upper member of the Cambro-Ordovician series is in itself complex. Prevalingly it is a slaty shale, occasionally it is a sandstone or shaly sandstone, or a simple shale; still more rarely it is almost a true slate, and very rarely a phyllite. The constituents vary from prevailing clay to quartz sand repeatedly in almost every locality. It is probable that as a rule the upper portions are the more heavily bedded and arenaceous. The rock is excessively affected by the dynamic movements that have at least twice disturbed it. A slaty cleavage in the more argillaceous members is most noticeable, but almost everywhere the strata are strongly tilted, crumpled, broken, faulted, or crushed in a most confusing way. This together with an original obscurity in bedding, and the obliteration by subsequent shearing of much that did exist, makes it impossible to reconstruct the complicated structure or compute the thickness of the formation. It is of such physical character as to absorb within its own limits much of the disturbing movements, and neither the formations above nor immediately below are so extensively and intimately affected. The formation is widely exposed and forms the bed rock over very large areas. Almost everywhere it is impervious to water, easy to penetrate by drill or tunnel, and resistant to decay. A few Ordovician fossils may be found, the most characteristic being *Dalmanella testudinaria*.

(23) *Wappinger limestone.*¹ (In part Cambrian, and in part

¹ The Wappinger Valley limestone of Dwight (1879) and Dana. The Wappinger limestone of Darton and others.



Bonticou crag. One of the peaks of the Shawangunk range. The rock is Shawangunk conglomerate. Bonticou tunnel passes beneath this point. (Photograph by Board of Water Supply)



A trench through Hudson River slates and sandstones for cut-and-cover aqueduct construction on the Newburgh division. (Photograph by Board of Water Supply)

Ordovician). The formation is prevailingly of a compact, fine texture, dark gray, either massive or strongly bedded limestone. Where the stratification is very plain there are light and dark layers and an abundant silicious intermixture. In many outcrops the rock is so massive that even the dip and strike are obscure. Some places the rock is fine crystalline, almost a micromarble. On weathered surfaces it almost always exhibits a crisscross etching which marks the traces of rehealed cracks. From these it is seen that many of the apparently massive compact beds have at one time been extensively crushed. In many places there is scarcely a square inch wholly free from these evidences. The formation is best exposed in the wide belt that extends southwestward from the vicinity of Poughkeepsie and crosses the Hudson at New Hamburg into the Newburgh district. It undoubtedly underlies the slates in the rest of the adjacent area. There are few fossils and they are rarely found.

(24) *Poughquag quartzite*. Below the Wappinger limestone and upon the upturned and eroded edges of the Highlands gneisses lies a quartzite of variable thickness but which reaches at least 600 feet. It is a strongly silicified quartz sandstone — a quartzite by induration. It is strongly bedded but seldom shaly. Traces of schistosity may appear in certain zones and this is somewhat strongly developed outside of the area at the type locality (Poughquag, N. Y.).

Only fragments of trilobite spines have been found in this formation within the district.

g Later crystallines south of the Highlands. South of the Highlands proper except at one locality (Peekskill creek valley and its southwestward continuation through Tompkins Cove and Stony Point) the rocks are all much more thoroughly crystalline. There are two formations, and in places traces of a third, above the Grenville gneisses (Fordham gneisses and associates). These are known locally as *Manhattan schist*, *Inwood limestone*, and *Lowerre quartzite*. In Westchester and New York counties the quartzite is rarely found, and in a considerable proportion of those places where it does occur its relations are more consistent with the gneisses below than with the limestone-schist series above. This is true indeed of the type locality (Lowerre). There are, however, at least two points where the occurrence favors the reverse interpretation, so far as any is shown, and therefore a quartzite may be regarded as finishing the series, and making uncertain but probably unconformable contact with the underlying gneisses.

This series together with the gneisses below constitutes the bed rock and controls the underground conditions for all of the line south of the Moodna valley, 50 miles above New York. All of the southern aqueduct, and the New York city distribution conduits are wholly concerned with these rocks, and two divisions of the northern aqueduct have a large proportion of their work in them.

It is not wholly clear what age these crystallines represent. It is certain that the underlying gneisses are Grenville and that the metamorphic quartzite, Inwood, Manhattan series, is Post-grenville. It is possible that these latter are also Precambrian. But usage following the correlations of Dana¹ and in the absence of as good evidence from any other source has regarded them as the Cambro-Ordovician crystalline equivalents of the Poughquag-Wappinger-Hudson River series of the north side of the Highlands. The writer has elsewhere shown² that the evidence and arguments are not all on one side and that considerable doubt may still be entertained on that point. There is no object in following that argument here or in modifying the treatment here followed of making them a distinct series. Even if they should prove to be the exact equivalents of the Hudson River-Wappinger-Poughquag series the formations are physically so different and require so different treatment in discussion that they must for our present purpose be regarded as an essentially distinct series. From that standpoint alone the usage here followed is justified. The Manhattan schist of Westchester county as a type differs as much petrographically from the Hudson River formation of the Newburgh district as the Catskill formation of Slide mountain differs from the Jameco gravels of Long Island. In a discussion where physical or petrographic character is in control there is no doubt about the advisability of treating the two separately.

(1) *Manhattan schist.*³ This is primarily a recrystallized sediment of silicious type. It occurs as a nearly black or streaked, micaceous, coarsely crystalline, strongly foliated rock. The chief constituents are biotite, muscovite and quartz. Quartz, feldspar,

¹ Dana, J. D. On the Geological Relations of the Limestone belts of Westchester county, N. Y. *Am. Jour. Sci.* 20:21-32, 194-220, 359-75, 450-56 (1880); 21:425-43; 22:103-19, 313-15, 327-35 (1881).

² Berkey, Charles P. "Structural and Stratigraphic Features of the Basal Gneisses of the Highlands." *N. Y. State Mus. Bul.* 107 (1907), p. 361-78.

³ Manhattan schist of Merrill. *N. Y. State Mus. 50th An. Rep't*, 1:287. Same as "Hudson schist," of N. Y. city folio no. 83.

garnet, fibrolite and epidote also occur in large quantity. Occasional streaks or masses are hornblendic instead of micaceous. These are interpreted as igneous injections. They are especially abundant on Croton lake and near White Plains.

It is essentially a quartz-mica schist. But it is almost everywhere very coarse textured and hardly ever exhibits the fine grained, uniform structure of typical schist. Its abnormal make-up — the predominance of biotite and quartz — is the best defense for its petrographic classification. The abundance of mica makes it a tough rock but not very hard. The joints and fractures formed in later movements are not healed and zones of bad shattering are susceptible to considerable decay. These crushings are sufficiently common to encourage borings to tap their content of water for small family use throughout Westchester county; but they do not represent large circulation in any case. On the whole, the rock if fresh is good and durable. It may, though rarely, carry considerable sulphide. Practically all of the strictly original sedimentation marks are destroyed by metamorphism. The formation has great thickness, but because of the destruction of original bedding lines by recrystallization and additional complication by most complex folding, shearing, crushing and faulting, the structure can not fully be unraveled and the thickness can not be estimated with any approach to accuracy of detail. But there is probably a thickness represented of several thousand feet.

(2) *Inwood limestone or dolomite.* This formation lies beneath the Manhattan. It is everywhere coarsely crystalline either massive or strongly bedded, often very impure with development of secondary (recrystallized) mica (phlogopite) and other silicates, especially tremolite. It is essentially a magnesian limestone or dolomite in composition. There is an occasional quartzose bed in the midst of the limestone as at East View. The upper beds are most charged with mica and occasionally beds attacked by alteration have much green, flaky chlorite. There are occasional interbeddings of limestone and schist as a transition facies.

The coarser grades upon exposure to weathering readily yield by disintegration to a lime (calcite) sand resembling roughly an ordinary sand in general appearance. At Inwood, the type locality, this disintegration is so pronounced that great quantities are readily shoveled up and used for various structural purposes in the place of other sand. This dolomite is especially liable, as now shown by extensive explorations, to serious decay to great depth. The underground circulation seems to attack the micaceous beds with great

success and in some places the residue after this solvent action is of the consistency of mud. A nearly vertical attitude of the beds accentuates the opportunity. The most troublesome piece of ground encountered on the whole line of the New Croton aqueduct, constructed in 1885, was in a weak zone and crevice in the Inwood near the village of Woodland on the margin of the Sawmill valley [*see* discussions of Bryn Mawr siphon and New York city distributions in part 2].

The thickness probably varies but in many places where there is only a narrow limestone belt it is due more to shearing or faulting out than to original thinning. The most satisfactory estimates are based on the explorations at Kensico dam and the field observations at 152d street. They indicate an approximate thickness of 700 feet. But in all cases either the margins are obscured or there is possibility of faulting to modify measurements. There are no fossils. Weathering and erosion has almost everywhere developed valleys or depressions especially small tributary valleys in all formations, but as pointed out years ago by Professor Dana the principal valleys prevailing coincide with the limestone belts.

(3) *Lowerre quartzite*. At Hastings-on-Hudson and again near Croton lake, there is a quartzite that appears to be conformable with the Inwood above. There is possibly more than 50 feet. It is a simple, clean quartzite. The other quartzites of Westchester and New York county have a more distinct relationship to the underlying gneisses with which they are conformable. The Lowerre of the type locality is of this second class. In the great majority of places where this bed would be expected to occur there is not a trace of it.

*h Older metamorphic crystallines (Grenville series).*¹ "The lowest and oldest, as well as the most complex in structure and rock variety, of all the formations of the Highlands region of southeastern New York is essentially a series of gneisses." Cutting these gneisses as intrusions of various forms are a great number and variety of more or less distinctly igneous types. In form they vary from small dikes or stringers to great batholithic masses; in composition, from the extremely basic peridotites or pyroxinites of

¹ This interpretation of the larger relations of the complex gneisses constituting the basis of the series, lying below the Manhattan-Inwood-Lowerre series, was presented by the writer under the title: Structural and Stratigraphic Features of the Basal Gneisses of the Highlands. N. Y. State Mus. Bul. 107 (1907). p. 361-78. The accompanying description is largely an abstract of this paper.

the Cortlandt series to the very acid granites of Storm King mountain or the granophyric pegmatites of North White Plains; and in relative age they likewise vary from a period antedating the chief early metamorphic transformation of the Grenville to Postmanhattan time. But these clearly igneous types attain a considerable prominence as separable units in the practical consideration of the problems of the project and on that account the chief ones will be more fully described under the next group.

The older portion — the various schists, banded gneisses, quartzites, quartzose gneisses, graphitic schists, and serpentinous and tremolitic limestone, forming the complex through which and into which the igneous masses have been injected — form together an interbedded series that was originally a sedimentary group. There is nothing known that is older in this region. Its characteristics and relations mark it as in all probability the equivalent of the "Grenville" of the Adirondacks and Canada.

No single type and no single characteristic can be given as a simple guide to the identification of this formation. The prevalence of certain varieties or groups of these and the strongly banded structure give a certain degree of character that forms a reasonable working base. The formation includes banded granitic, hornblende, micaceous and quartzose gneisses; mica, hornblende, chlorite, quartz and epidote schists; garnetiferous, pyritiferous, graphitic, pyroxenic, tremolitic, and magnetitic schists and gneisses; crystalline, tremolitic, and serpentinous limestones, aphi-dolomites, serpentines and quartzites; pyrite, pyrohitite and magnetite deposits. This is the basal series. But it is complicated by a multitude of bands of granitic and dioritic gneisses that represent injections of igneous material at a time sufficiently remote to be subjected to most of the early metamorphic modifications. The equally abundant occurrences of quartz stringers and pegmatite lenses though of later origin can not be separated from this complex mass and the whole must be regarded as a physical unit. The occurrence of interbedded limestones and quartzites together with a variety of conformable schists and banded rocks, marks the formation as essentially an old recrystallized sediment.

No member of this older unit of the basal complex is sufficiently prominent to indicate a great break or change up to the time of the first great dynamic movements and igneous outbreaks. The following comparatively constant members are sometimes persistent enough to be considered formational units, but even more commonly

are obscure as to boundaries or are of too small development to map separately.

(4) *Interbedded quartzite*. Always a quartzite schist and always exhibiting conformity with the banded gneisses and schists. This is regarded as the uppermost member.

(5) *Fordham gneiss* (Banded gneiss). Granitic and quartzose black and white banded gneisses and schists of very complex composition and structure.

(6) *Interbedded limestones*. Crystalline. Interbedded, very impure, serpentinous and tremolitic, granular dolomites, usually 2 to 50 feet thick, possibly reaching a thickness of more than 100 feet in a few cases.

(7) *Older intrusive gneisses*. Variable types, mostly granites or diorites, strongly foliated sills.

Many are of very obscure relations. The line of close distinction between recrystallized sediment, segregations accompanying that change, and true igneous injection can not be drawn.

i **Special additional igneous types.** Under this heading are included the massive or little modified, not at all or only moderately foliated, igneous masses of later origin and local rather than regional development. In some cases, however, they are of decidedly controlling importance in the local geology and rise to the status of definite formations. The most noteworthy of these within reach of the aqueduct explorations are:

- (8) The Storm King Mountain gneissoid granite
- (9) The Cat Hill gneissoid granite. (central Highlands)
- (10) The Cortlandt series of gabbro-diorites (near Peekskill)
- (11) The Peekskill granite (east of Peekskill)
- (12) The Ravenswood granodiorite (Long Island City)
- (13) The pegmatite dikes and lenses (segregational aqueo-igneous type)

(8) *The Storm King gneissoid granite* is one of the largest of the clearly igneous and less completely foliated types. It constitutes the whole of Storm King mountain and the larger part of Crows Nest on the west side of the Hudson, and, crossing the river, forms the chief rock of Bull hill and Breakneck ridge. It is a rather acid, coarse grained, reddish granite with considerable gneissoid structure in a large way [*see* Hudson river crossings, pt 2].

(9) *The Cat Hill gneissoid granite* is not essentially different from the Storm King type as a physical unit. Its occurrence at a



South portal to Garrison tunnel on the Peekskill division. The rock is a badly jointed granite belonging to one of the intrusives of the older gneisses. (Photograph by Board of Water Supply)

different point (Cat hill), widely separated by other types from the Storm King locality, and in rather large development, is worthy of separate note. It is cut, of course, in the long tunnel through Cat hill.

(10) *The Cortlandt series of gabbro-diorites* occupies an area of about 20 square miles between Peekskill and the Croton river, nearly all on the east side of the Hudson. It includes a very complete range of coarse grained, massive, igneous rocks from soda granites, grano-diorites and quartz-diorites to true diorites, norites, gabbros, pyroxenites, and peridotites. They doubtless represent stages or portions in the differentiation of a magma. The interrelations are only partially determinable, and the petrographic distinctions in detail are not useful here. The area occupied by the Cortlandt series has an uneven hilly surface with no structural trend, and makes the most striking contrast to the ridge and longitudinal valley structure of the rest of the region of the crystallines.

(11) *The Peekskill granite*, a white, or pink massive, very coarse grained, soda granite, occupying approximately 4 square miles immediately north of the Cortlandt area 2 miles east of Peekskill, is believed to be genetically related to the Cortlandt series. The evidence in favor of such a relationship has been gathered in the prosecution of this work and has not been published. But it may be said that the textures, structure, age, relationship to older crystallines, interrelations with the Cortlandt series, consanguinity of mineralogy, and composition all point toward the above relationship. In essential relations, therefore, it is the acid extreme of the Cortlandt series. Its economic features, however, are of sufficient importance and its easy differentiation from the regular Cortlandt types require that it should have separate treatment.

(12) *The Ravenswood grano-diorite* occurs chiefly in Brooklyn. It is a slightly foliated mass intrusive in the Fordham gneiss and is doubtless connected in origin with the sources of many of the hornblendic intrusive bands in the Fordham and Manhattan formations in the district. It covers a known area of about 5 or 6 square miles and may be more extensive. The rock is suitable for structural material and has required consideration in the study of "Distributary conduits" [see pt 2 East River section].

(13) *Pegmatites*. The pegmatites and pegmatitic granophyric masses of all kinds are of almost universal distribution in the foliated crystallines. They vary from quartz bunches or stringers to pegmatitic lenses and irregular masses, and to definite granitic

or pegmatic dikes. In many places they constitute a large proportion of the formation in which they occur. They doubtless vary in age, but for the most part seem to belong to the later period of metamorphism. Many of them are massive and largely free from foliation. They no doubt have a complex origin between simple aqueous segregation on the one side and true igneous intrusion on the other.

Summary of formations

Group a Quaternary deposits

- | | | |
|---|---|---|
| <p>(1) Glacial drift
Till and modified drift, extra
marginal outwash, sands and
gravels, etc.</p> | } | <p>Occurs as a surface
mantle over nearly all
of the region under
discussion, except the
immediate sea margin</p> |
|---|---|---|

UNCONFORMITY

Group b Tertiary and Cretaceous deposits

- | | | |
|---|---|--|
| <p>(2) Tertiary outliers
(a) Pliocene littoral deposits
(Bridgetons?)
(b) Miocene "fluffy" sand (Beacon
hill)</p> <p>(3) Upper Cretaceous beds
(a) Ligniferous sand (marl series)
(b) Matawan beds (clay marls)
(c) Raritan (clays and sands)</p> | } | <p>Confined to Long Is-
land, Staten Island
and the New Jersey
coast</p> |
|---|---|--|

UNCONFORMITY

Group c Jura-Trias formations

- | | | |
|---|---|---|
| <p>(4) Palisade diabase intrusion
(5) Newark series of conglomerates,
sandstones and shales</p> | } | <p>Confined to the west
side of the Hudson
south of the High-
lands</p> |
|---|---|---|

UNCONFORMITY

Group d Devonian strata

- (6) Catskill, white and red conglomerate (1725 feet)
- (7) Oneonta (upper flagstone) (3000 feet)
- (8) Ithaca and Sherburne (lower flagstone) (500 feet)
- (9) Hamilton and Marcellus shales (flagstone and shales) (700 feet)
- (10) Onondaga limestone (200 feet)
- (11) Esopus and Schoharie shales (silicious) (800 feet)
- (12) Oriskany and Port Ewen transition (100 feet)
- (13) Port Ewen limestone and shale (150 feet)
- (14) Becraft limestone (75 feet)
- (15) New Scotland shaly limestone (100 feet)
- (16) Coeymans cherty limestone (75 feet)

Confined to the Catskills, the Esopus and Rondout valleys, the northern extension of the Shawangunk range, and Skun-nemunk mountain near Cornwall

Group e Silurian strata

- (17) Manlius limestone (70 feet)
- (18) Cobleskill limestone and cement beds (30 feet)
- (19) Binnewater sandstone (50 feet)
- (20) High Falls shale, including small limestone beds (75-80 feet)
- (21) Shawangunk conglomerate (250-350 feet)

Confined to the Rondout and Esopus valleys and the northerly extension of the Shawangunk range, through the cement region of Rosendale, Binnewater, Rondout and Kingston, and a small outlier at Skun-nemunk mountain

UNCONFORMITY

Group f Cambro-Ordovician formations

- | | | |
|---|---|---|
| <p>(22) Hudson River slates, shales, and sandstones (very thick) (Ordovician) more than 2000 feet</p> <p>(23) Wappinger limestone (1000 feet) (in part Cambrian and in part Ordovician)</p> <p>(24) Poughquag quartzite (600 feet) (Cambrian)</p> | } | <p>Especially prominent as surface formations in the Shawangunk range, the Wallkill valley, and the region eastward and southward to the Highlands, on both sides of the Hudson</p> |
|---|---|---|

Group g Later crystallines (South of the Highlands)

(Uncertain age)

- | | | |
|--|---|--|
| <p>(1) The Manhattan schist, a thoroughly and coarsely crystalline sediment of uncertain age—generally supposed to be equivalent to the Hudson River slates, (Ordovician) but here separated without necessarily raising that question because of their very different physical and petrographic character</p> <p>(2) Inwood limestone (or dolomite), a magnesian crystalline limestone of uncertain age, generally supposed to be the equivalent of the Wappinger (Cambro-Ordovician), but here enumerated separately without necessarily raising that question because of their very different lithologic character and associates</p> <p>(3) Lowerre quartzite, an occasional quartzite of uncertain relations and very limited development</p> | } | <p>Confined to the region east of the Hudson river and south of the Highlands proper, occupying the region from the Highlands to Long Island</p> |
|--|---|--|

UNCONFORMITY

Group h Older crystallines (Highlands gneisses)

- (Grenville series of metamorphics and intrusives — Precambric)
- | | | | |
|---|--------------------|---|--|
| <p>(4) Interbedded quartzite. A quartzose schist</p> <p>(5) Fordham gneiss (chiefly sedimentary). Granitic and quartzose banded gneisses and schists of very complex development</p> <p>(6) Interbedded limestones (Grenville) associated with the Fordham gneisses</p> | } Grenville Series | } | <p>Formations characteristic of the Highlands and some of larger ridges extending southward to New York city. A series, which in petrographic variety, is as complex as all of the rest of the formations of the region together</p> |
| <p>(7) Old intrusions. Large and variable masses of granitic gneisses of igneous origin cutting the Grenville series, such as Storm King granite, Cat Hill granite, etc.</p> | } | } | } Postgrenville in age |

Group i Special additional igneous types

- | | | | |
|---|---|---|---|
| <p>(8) Storm King gneissoid granite, Storm King-Breakneck district</p> <p>(9) Cat Hill gneissoid granite. Garrison district</p> <p>(10) Cortlandt series of gabbro-diorites. Peekskill-Croton district</p> <p>(11) Peekskill granite. A boss, related to the Cortlandt series. Peekskill district</p> <p>(12) Ravenswood grano-diorite. A boss. Brooklyn, Long Island City and Southern Manhattan</p> <p>(13) Pegmatites. Dikes, lenses, segregations of general distribution</p> | } | } | <p>These are masses of strictly igneous origin (except the pegmatite) and of larger development which either because of their abundance (<i>pegmatites</i>) or large area (<i>Cortlandt</i>) or economic features (<i>Peekskill</i>) or important bearing upon the plans of the aqueduct (<i>Storm King</i>) are worthy of separate note.</p> |
|---|---|---|---|

3 Major structural features

In addition to the simpler structural characters of the strata, already sufficiently emphasized in the individual descriptions, there are numerous others of more general relation whose value and influence it is necessary to consider in many of the practical problems. Those of most importance are the unconformities, folds and faults. They are directly related to continental elevation and subsidence, to mountain forming movements and denudation processes, to metamorphism and to igneous intrusion.

a Sedimentation structures. In the younger strata the principal structures are those of bedding, stratification, conformable succession, etc., characteristic of all sediments of such variety of type. These are prominent in the older groups of formations down to the crystallines, but the earlier Paleozoics are also affected so profoundly by folding and faulting that attention is more concerned with these induced or secondary structures.

b Unconformities. Time breaks, with more or less disturbance of strata and accompanied by erosion, are numerous.

(1) That between the glacial drift and the rock floor is the most profound. It causes the glacial drift to lie in contact with every formation of the region from the oldest gneisses of the Grenville series of the Highlands to the traces of Miocene beds of Long Island.

(2) The interval between the Pliocene and the Upper Cretaceous beds is more obscure and hardly reaches the importance of an unconformity. It is probably more nearly of the value of a disconformity or of an overlap, and the very limited development of the overlying beds in the region gives little chance for determining relations in much detail.

(3) The overlap and unconformity between the Cretaceous and Triassic. A condition determinable only on the New Jersey side of the Hudson river.

(4) The unconformity between the Triassic and underlying formations of different ages. An interval representing mountain development and extensive erosion, in which the chief movement probably belongs to the close of Paleozoic time and includes the Appalachian folding.

(5) Unconformity between Siluric and the Ordovician strata. An interval representing mountain development, folding and erosion, in which the movement known as the Green Mountain folding took place.

(6) Unconformity between the Poughquag (Cambric) quartzite and the underlying crystallines. An interval in all observable cases of great length and profound changes involving mountain folding, metamorphism of the profoundest sort, and extensive erosion.

(7) Among the crystallines of the south side of the Highlands there is one break of similar importance, between the Inwood limestone and the underlying gneisses. Whether or not it is the same as no. 7 above is not clear, but even if it represents the same break the relations are somewhat different in degree and character because of the lack of quartzite in almost all cases.

Within the gneisses of the Grenville series and their associates of all kinds there are no breaks of the unconformity type known. The contacts are eruptive in character, or are displacements instead.

c **Folds and mountain-forming movements.** All of the formations from the oldest up to and including the Lower Devonian strata are folded. Many of the smaller (minor) folds exhibit complete form in the stream gorges of the district, but all of the larger ones, the main folds, have in earlier time been eroded to such extent that the series is beveled off and only the truncated edges are to be seen, exhibiting strata standing more or less perfectly on edge, and making restoration of the form a very difficult or impossible task. This is only partially accomplished in the Siluro-Devonian margin along the Shawangunk range; it is more complete in the Cambro-Ordovician north of the Highlands, and it reaches its most perfect development in the crystallines of the Highlands and New York and Westchester counties. These differences correspond roughly to the differences in age of the strata, and, taken together with the evidence of the profound unconformities, indicate that mountain-forming movements of far-reaching importance visited the region no less than three times. Each time of such disturbance, of course, the underlying older series was affected by the movements of that epoch in addition to any previous ones, and as a consequence the older is to be expected to show more complexity of such structures. Each succeeding series separated by such activity is therefore one degree simpler in structure.

Of these three epochs of great disturbance, one is (1) Precambrian and corresponds to the time interval marked by the unconformity between the Poughquag quartzite and the gneisses; a second (2) is Postordovician and corresponds to the time interval marked by the unconformity between the Hudson River slates and the Shawan-

gunk conglomerates, and the last (3) is Postdevonic (probably Postcarbonic, judging from neighboring regions of similar history) and has left as its most important evidence in this district, the excessively complicated sharp foldings and thrusts of the Shawangunk range and its extension in the Rosendale cement district.

Kinds. As to forms produced there are no usually described types that are not to be found here. The simpler forms of anticlines and synclines, both open and closed, symmetrical and unsymmetrical and overturned, are all common. The isoclinal is common in the gneisses. In each epoch of folding the compression forces were effective chiefly in a northwest-southeast direction producing arches and troughs whose axes trend northeast-southwest. This is the trend of the main structures throughout the region.

The extent of crustal shortening accomplished by this series of compressions is undetermined, but that it amounts to a total of many miles is indicated by the fact that over broad areas the strata stand almost on edge. Furthermore, in the older Highlands and in portions of the Hudson river districts the folds have been slightly overturned so that commonly the strata on both limbs dip in the same direction (toward the southeast). This seems to indicate a strong thrust from the southeast. All stages between the gentlest warping to strongly overturned folds, and from minute crumbling to folds of great extent and persistence are to be seen.

The effect of all the folding is chiefly to present a series of upturned strata to erosion and encourage a subsequent development of valleys along the softer beds bordered by ridges of the more resistant types.

As the axes of the folds lie in a northeast-southwest direction, this gives a marked physiographic development of ridges and valleys of the same trend, a most conspicuous topographic feature of southeastern New York.

d Faults. Accompanying the folding in each epoch, and especially the stronger overthrust movements there has been a tendency to rupture and displacement. These breaks are known as faults. Multitudes of them are of minute proportions and practically neglectable in a broad view, but many also are of large extent, traceable across country for many miles and indicating displacements in some cases of many hundreds of feet. For the most part these faults are of the thrust type and wholly consistent with the folds in origin. They run generally in a northeast-southwest direction, especially the larger ones, and frequently form the separation planes between different formations. Occasional cross



A fold in the New Scotland limestone on Rondout creek. (Photograph by Columbia University Summer School in Geology, 1908)





A thrust fault in the limestone beds on Rondout creek near Rosendale. (Photograph by Columbia University Summer School in Geology, 1908)

faults occur (with northwest-southeast direction across the strike), but so far as is known they are always of minor consequence. In rare instances, the trace of a fault line on the surface describes curious curves, such as that at Cronomer hill above Newburgh, apparently inconsistent with the chief structural trend, but a study of the whole geologic relation in such cases shows them to be connected with the projecting spurs of underlying formations which in any large thrust movement plow their way with some success through the younger overlying, less resistant, strata. They differ in no material way from the other more simple looking lines.

Both normal and thrust faults occur, but the thrust type appears to be most common.

The amount of displacement or throw is extremely variable. The larger faults represent movements of several hundred feet. In rare cases the movement may be as much as 2000 feet.

The effects may be grouped as follows: (1) the appearance of formations out of their normal order, i. e. contacts between formations that do not normally lie next to each other; (2) the production of escarpments, i. e. steep cliff-bordered ridges; (3) the development of zones of more or less extensively crushed rock along the principal plane of movement; (4) the determination of location for stream courses and gulches and valleys that cross the formations.

All of these effects are more noticeable and better preserved for the later movements than for the earlier ones. Many of those dating back to the earliest epoch, affecting only the crystalline rocks of the Highlands, are not readily detected. Most of the breaks have been healed by recrystallization and the contacts are often as close and sound as any other part of the formation.

But this is not so true of the later epochs — and in them a good deal depends upon the type of rock affected. The more brittle and hard and insoluble types are more likely to still have open seams and unhealed fractures than the softer and more easily molded formations. In some of these, recent water circulation has still further injured the fault zones by introducing rock decay to considerable depth. Because of the more ready circulation in them, it is noticeable that some of the extensive decay effects are produced in crystalline rocks that otherwise very successfully resist destruction. On the whole the softer clay shales and slates are less likely to preserve open water channels of this sort than any other formation of the region.

No part of the region is wholly free from faulting effects, except perhaps a part of Long Island. The Catskills also are very little affected — so little that this type of structure has not require consideration in the vicinity of Ashokan reservoir. But all parts of both the northern and southern aqueduct system have had this feature to consider.

Further discussion of the specific local problems introduced by faulting and folding is given under the problems of part 2. A considerably more extended comment on the age of fault movement is given under the heading "Postglacial faulting."

4 Outline of geologic history

Most of the general features of geologic history have been involved more or less in the foregoing discussion. It is impossible to wholly separate matters that are so intimately inter-related even though it is convenient to think of or consider one phase at a time. But it may serve a useful purpose to summarize the steps of progress as illustrated by local geology from the earliest geologic time to the present.

a **Earliest time.** (Prepaleozoic, Agnotozoic, Proterozoic, or Azoic Era). There is little doubt that the oldest rocks known in this region are representatives of a time of regular sedimentation. Conditions favored the deposition of silicious detritus of variable composition with an occasional deposition of lime, nearly always in very thin beds. What these sediments were laid down upon or where they came from are unsolved questions. The remnants of them that are still preserved are the basis of the "Grenville series" as interpreted in this area, and are the basal (oldest) members of the "Fordham" or "Highlands gneisses."

How long ago this series was deposited is not known. It can be stated only approximately even in the rather flexible terms used in historical geology. It is older than any Paleozoic strata (Precambrian), probably very much older. It is even possible that this series is as much older than the Cambrian as that period is compared to the present. In short, it is not known, and there is apparently little immediate likelihood of finding out even to which of the several subdivisions of the Prepaleozoic this series belongs. It is certain that before the Cambrian sandstones of the Paleozoic era had begun to form, this older series was disturbed by crustal movements, folded, metamorphosed, intruded by igneous injections, elevated above the water (sea) level of that time and eroded by surface agencies. These movements and steps there is no doubt of.

When subsidence¹ again depressed the area beneath the sea the deposition of sands that we now call Cambric (Poughquag) quartzite began.

b **Early Paleozoic time.** With the sedimentation upon this old crystalline rock floor a long time of apparently continuous deposition began which ultimately resulted in the accumulation of several thousand feet of sandstones, limestones, and sandy or clayey shales that are now known as the Cambro-Ordovician series (Poughquag-Wappinger-Hudson River series). But at the close of Ordovician time or late in that period another crustal revolution began. The whole region was again compressed into mountain folds, faulted, sheared, metamorphosed, elevated above sea level, and subjected to erosion. This corresponds to the Green mountains folding of Vermont.

With the next subsidence and a return of sedimentation a new series began to form. The break marking the occurrence of all these changes, known locally as the Postordovician unconformity, represents a considerable portion of Silurian time.

c **Middle Paleozoic time.** The earliest deposits of this series, which continued to accumulate through late Silurian and all of Devonian time, were heavy conglomerates very unevenly distributed over the new rock floor. These are the so called Shawangunk conglomerates, a formation that within the boundaries of this immediate area and within a distance of 20 miles varies from a thickness of more than 300 feet to almost nothing. But for the most part, sedimentation was regular and fairly continuous and of immense volume. The whole series of conglomerates, sandstones, shales, grits and limestones belonging to the later Silurian and the Devonian are included. Not all are believed to be marine however. The Catskill and Shawangunk conglomerates may well be of continental type.

Long after the deposition of all of these strata another crustal disturbance, for at least the third time, repeated the process of mountain-folding and erosion. This was the time of the Appalachian mountain-folding. In this region it caused a wonderfully complex development of folds and faults that are especially important and determinable as to type and age in the Rondout cement region. The movement, of course, affected all of the older formations as

¹ There may possibly be an intermediate stage, practically a duplication of the whole as given above, between the very oldest and the Cambric, represented in the "later crystallines," but this may as well be neglected for the present.

well, but on them, already disturbed by earlier displacements, the features chargeable to the disturbance can not always be distinguished from older ones. All three of the mountain-forming compressions seem to have been controlled by the same relationship of forces and adjustments of movement, for the results are in each case the production of folds or faults of similar orientation and a final structure of uniform trend.

Deposition had been going on for ages, chiefly on the west and north side of the older crystallines; but with a return of sedimentation a decided reversal is noted. The Atlantic border is depressed and much of the interior region seems not to have been subjected to further deposition from that time even to the present.

d Mesozoic time. Again conglomerates, sandstones and shales were laid down upon an eroded floor. From their condition and lithology it is believed that they are partly of continental, flood plain, origin. The series is thick, generally assigned to the Triassic period and is extensively developed. During the time of accumulation and to some extent subsequent to it, there was extensive igneous activity pouring out and intruding basic basaltic matter in large amount. The Palisade diabase sill, and the Watchung Mountain basalt flows are the best examples.

At a later time small faulting occurred making frequent displacements in this series. But mountain-folding has not again visited the region. Such breaks as there are, are of the nature of overlaps and disconformities rather than of the revolutionary history indicated by a true unconformity. One of these intervals occurs in the Mesozoic between the Triassic and Cretaceous. Above it the thick series of Cretaceous shales, marls, sands and clays are developed. Succeeding this series a similar interval represents the earliest Cenozoic time.

c Early Cenozoic time. The earliest Cenozoic (Eocene and Oligocene) has no sedimentary record within this region.

There are small remnants of deposition representing Miocene and Pliocene time. Above these again the record is blank up to the time of the glacial invasion.

f Late Cenozoic time—glacial period. By some combination of conditions not very well understood, the chief features of which no doubt are,—(1) continental elevation and (2) shifting of centers of precipitation and (3) modification in the composition of the atmosphere, a period of excessive ice accumulation was inaugurated. Ice finally covered immense continental areas and

from its own weight by continuous accumulation spread out (flowed) from great central areas toward the margins. There is clear evidence of interruptions or advances and retreats of this general movement many times. But the same type of work and similar results were attained in each case. The chief features of this work was the moving of rock material frozen in the ice to long distances and the deposition of it again, more or less modified by its contact with the ice or by the effect of water upon its release, at other places and with entirely new associations. The tendency to ice accumulation was finally overcome to sufficient extent for the inauguration of the present condition of things. Whether it is a permanent change or only an interglacial interval is not clear. But the ice has withdrawn to the mountains and the polar north at the present time. It has not occupied the surface of this region probably within the last 40,000 years, and perhaps for a much longer time.

5 Outline of geographic history — physiography

The surface features of a country are the result of the working out of a long and complex series of processes with and upon the materials of the rock floor or bed rock. The relationship of surface features to the formations that occur in the rock floor and their stages of development, in short, an interpretation of their origin and meaning, constitutes geographic history or physiography. It differs little in essential character from geologic history, of which it is only a special branch, i. e. the history of surface configuration. And it can not be appreciated or understood except in the light of a thorough knowledge of stratigraphic and structural geology. In individual cases or particular regions the geologic knowledge must also be specific.

a **Early stages.** Occasional glimpses of surface features, and some scattered facts about their development are to be gathered of older continental existence. Surface features characteristic of their time were developed in the great intervals between each successive period of continuous deposition. Traces of them are involved in the unconformities of the geologic column already shown in the discussion of geologic history. Hills, valleys, streams, shores and all the appropriate assortment of forms must have existed. But they could not have been like those of the present in many minor features — especially in arrangement and distribution — because the bed rock of those times had only in part reached the complexity of

structure and composition now belonging to it. Many items of importance are indicated in some of these early periods. For example, the sea encroached on the land borders repeatedly from the westward — especially throughout Paleozoic times, while in Mesozoic and Cenozoic times the evidence of shiftings of sea margins is confined to the east and southeast borders, and likewise probably no near by place has been continuously beneath the sea.

But the unraveling of these conditions is obscured by subsequent events. Land surfaces that once were, became covered by later sediments. The physiography of those times, Paleogeography, as well as paleogeography, is therefore a difficult and intricate line of investigation. With these ancient surfaces the discussion of present features has little to do. Here and there the present surface cuts across and exposes the edges of an older one giving traces of the old profile; but in most cases it is so distorted by the foldings and other displacements belonging to a later period that a restoration of the original continental features is a task fit for the most highly trained specialist.

The surface as it now exists, and the rock floor modified only by the inequalities of the loose soil mantle, yields more readily to investigations of origin and history.

b **History of present surface configuration.** On some portions of the region there seems to have been no deposition since the close of Paleozoic time. Throughout most of Mesozoic and Cenozoic times, therefore, those regions probably have been continuously land areas (continental) and have been subjected to the agencies of erosion. This applies particularly to the Highlands region and the Catskills and the Shawangunk range and intervening country.

What the surface configuration was like in the early stages is wholly unknown. In the beginning, mountain-folding — the Appalachian folding — was in progress and the features were probably those of partially dissected anticlinal folds. With the progress of erosion the Triassic deposits were accumulated along the eastern border, probably on the continental slopes. Subsequently, further elevation extended erosion over the Triassic areas also and the Cretaceous beds were laid down on the margin. The general lines of development have been the same from that time to the present. Each successive important formation less heavily developed and forming a band outside of and upon the older one — the whole now constituting a series of successive belts the oldest of which is far inland and the newest at the sea margin.

Therefore, when long periods of denudation are referred to, it is well to appreciate that this is especially applicable to the interior, that the sea margins are comparatively new, and that certain of the inland areas were suffering erosion long before the rock formations that lie beneath and form the rock floor of the sea border districts were in existence.

Cretaceous peneplain. It appears from studies of these problems in a broad way, and, drawing upon generalizations from continental features of a much larger field than that of the present study, that the continental region of which this forms a part must, in the earlier periods, have remained in comparatively stable equilibrium for an extraordinarily long time. So long a time elapsed that most of the area was reduced by erosion to a monotonous plain (peneplain) at a very low altitude, probably not much above the sea (base level). Only here and there were there areas resistant enough or remote enough to withstand the denuding forces and stand out upon the general plain as remnants of mountain groups (Monadnocks). Possibly the Catskill mountains of that day had such relation.

This reduction of surface feature it is believed was reached in late Cretaceous time. The continent stood much lower than now. Portions that are now mountain tops and the crests of ridges were then constituent parts of the rock floor of the peneplain not much above sea level. This rock floor was probably thickly covered with alluvial deposits (flood plain) not very different in character from the alluvial matter of portions of the lower Mississippi valley of today.

Upon such a surface the principal rivers of that time flowed, sluggishly meandering over alluvial sands and taking their courses toward the sea (the Atlantic) in large part free from influence by the underlying rock structure. The ridges and valleys, the hills, mountains and gorges of the present were not in existence, except potentially in the hidden differences of hardness or rock structure. Such conditions prevailed over a very large region — certainly all of the eastern portion of the United States. This so called Cretaceous peneplain is the starting point in development of the geographic features of the present.

Continental elevation. Following upon this period of stability and extensive denudation came one of continental elevation. How much above sea level this raised the areas under present discussion may not be determined, but that it was a sufficient amount to

rejuvenate the streams and permit them to begin the sculpturing of the land in a new cycle of erosion is perfectly clear. As soon as the elevation and warping of the continental border made its influence felt in the increased activity and efficiency of the streams (rejuvenation) they began transporting the alluvium of their flood plains and to sink their courses through this loose material to bed rock. The final result of long continued denudation under these conditions in early Tertiary time was the removal of the loose mantle and the beginning of attack on bed rock (superimposed drainage). The streams formerly flowing on alluvium that had now cut down to rock found themselves superimposed upon a rock structure not at all consistent with their former courses. With the progress of erosion on this rock floor all these differences of structure, such as the differences in hardness of beds, the trend of the folds, the strike of the faults, the igneous masses, etc., were discovered and the streams began to adjust their courses to them. Valleys were carved out where belts of softer rock occur, ridges were left as residuary remnants where belts of harder rock exist, and the surface (relief) took on some of the character of present day lines. That is, the principal mountain ranges of that time were the same as those of today in position and trend; but they had not so great apparent height because the intervening valleys had not yet been cut so deep. The principal escarpments of that time were due to the same structural lines as those of today, only they have shifted somewhat along with the general retreat of all prominences by the forces of weathering and erosion.

In the course of this work of sculpturing and the shifting of valleys and divides and escarpments and barriers into constantly greater and greater conformity with rock structure, it came about by and by that practically all of the smaller and tributary streams had so completely adjusted themselves to their geologic environment that their valleys almost everywhere followed along the softer beds (subsequent streams), the divides were chiefly of harder beds, the trend of both were almost everywhere parallel to the strike of the rock folds and other structures (adjusted drainage). This undoubtedly involved in many cases a very radical change of stream course, and in some cases an ultimate reversal of drainage to such extent that tributaries were deflected inland against the course of the master streams and in some cases actually flowed many miles in this reversed direction before finding an accordant junction (retrograde streams). At least three of the streams of

southeastern New York are still of this type—the Wallkill, the Rondout and the lower portion of the Esopus.

But the larger rivers, the great master streams, of the superimposed drainage system, in some cases were so efficient in the corrasion of their channels that the discovery of discordant structures has not been of sufficient influence to displace them, or reverse them, or even to shift them very far from their original direct course to the sea. They cut directly across mountain ridges because they flowed over the plain out of which these ridges have been carved and because their own erosive and transporting power have exceeded those of any of their tributaries or their neighbors. They are superimposed streams (not antecedent), they have, with their tributaries, settled down in the ancient plain, and, by their own erosive activity, have carved the valleys deeper and deeper, cutting the upland divides narrower and narrower until now only here and there a ridge or a mountain remnant stands with its crest or summit almost reaching up to the level of the ancient peneplain on which the work began. If the transported matter could all be brought back and replaced in these valleys the old plain might be restored, but the work would immediately begin all over again.

Of these great master streams the Hudson is the only local representative [*see Study of the Hudson River gorge in part 2*].

Tertiary incomplete peneplanation. Such processes, if allowed to continue on a stable continental region, would ultimately reduce the land for a second time to a monotonous plain (complete cycle of erosion). The beginnings of such a plain would be made in the principal stream valleys upon reaching graded condition. Their lateral planation and the development of flat-bottomed valleys would begin at about the level that the plain would stand in the final completed stage. The difference of elevation between the ridge crests or hilltops and these flat valleys, i. e. between the old peneplain and the new unfinished one would be an approximate measure of the amount of the continental elevation that instituted the new cycle.

But judging from such remnants of this later plain as are to be seen, the two, i. e. the old Cretaceous peneplain and the new Tertiary peneplain are not parallel. Toward the southeast, toward the sea, the older plain descends more rapidly than the younger and intersects it. Both pass beneath sea level in that direction. The difference between them therefore varies with locality from

0 feet to perhaps 2000 feet within the borders of the area (continental tilting or warping).

Late Tertiary reelevation. Traces of such an intermediate and incomplete peneplain are to be seen in the compound nature of the large valleys of the present day. Most of them are essentially broad valleys into the bottoms of which narrower valleys and gorges are cut. The tops of the minor hills and ridges of the broad valleys represent the intermediate Tertiary peneplain that was interrupted in its development before completion (interrupted erosion cycle). The inner narrow valleys indicate that for the second time a regional elevation rejuvenated the streams and they began their work of cutting to a new grade. They have made a good beginning at this task, and as a consequence have carved some relief in the old valley bottoms. These new streams have not yet reached a graded condition.

When the glacial ice began to invade this region all of the surface features had had such a history. Leaving out of account minor fluctuations of elevation and depression, of which there may have been several of too transient character to make a lasting impression on the topography, the stages become comparatively few and the general tendencies are easily understood.

The measurable differences of elevation between the Cretaceous and Tertiary peneplains give some reasonable conception of the amount of the first continental or regional elevation. Concerning the altitude reached in subsequent regional elevation there is less certainty. None of the streams, not even the master streams such as the Hudson, reached grade, for it exhibits strictly a gorge type not only within the present land borders, but it is now known to show gorge development far beyond the present coast line. Judging from the Hudson, therefore, it seems necessary to conclude that this continental region stood at a much greater elevation in some portions of the later period than had formerly prevailed. Probably the maximum elevation immediately preceded the glacial invasion.

Conservative estimates as to the amount of elevation of that time in excess of the present would place it at not less than 2000 feet. Much more than that is believed to be indicated, possibly 5000 feet or more.

In the meantime, the master stream, the Hudson and several of the tributaries cut into their valley bottoms to such extent as to make typical gorges so deep that their beds now, since the sub-

sidence, lie much below sea level. The Hudson bed is of this character throughout its course from Albany to the Atlantic, and in the Highlands, 60 miles inland, the known rock bed at one point is more than 700 feet below sea level.

In late glacial time there was still greater subsidence (50-100 feet) than the present as is indicated by terraces above present water level and the deltas formed at the mouths of tributary streams.

Such in general outline is the history of successive conditions governing the topographic development of the rock floor. The succession of periods of stability, elevation, stability again, reelevation and subsidence have had an effect on all sorts of formations, but the extent of the impress and its permanence varies greatly in the different districts. It is not possible to study these differences in detail here. They are the minor and special local characters that are in control at particular localities. In discussions of special problems some of these are taken up in more detail. But in each case the general history as outlined above, together with the modifying influence of known local structure and stratigraphic character are the foundations of a working understanding [*see* Hudson River crossings, Moodna creek, Rondout valley, etc., pt 2].

Pleistocene glaciation. An additional modification and one largely independent of and largely inconsistent with the distribution of the smaller features of the rock floor is introduced by the glacial drift. It covers almost everything, but so unevenly as to largely destroy some of the detail. It is in places more than 350 feet thick (as in the Moodna and Rondout valleys) and in others it amounts to nothing. It covers the narrow ravines and gorges heaviest and has altered the courses of many of the smaller streams, the original channels being hopelessly buried. The result has been chiefly one of reducing the ruggedness of outline that prevailed along the newer gorges of late preglacial time.

Besides this the usual surface forms characteristic of glacial deposits, occur — the kame, the drumlin, the esker, the hill and kettle topography of the terminal moraine, the overwash plain, the delta, the lake deposit and the gentle undulations of the ground moraine. These are superimposed on the rock floor features. Both are equally important to understand in the problems that have been encountered. Which set of factors is to be most regarded in a given case depends wholly upon the locality and the kind of enterprise or work it is proposed to undertake.

c **Physiographic interpretation.** Rock floor contour is an expression of the differences in character and structure of the bed rock formations themselves, brought about by ordinary surface weathering and transporting agencies, varied in their action and effects only by certain differences in elevation above the sea. It is apparent therefore that it would be possible by careful observation of surface features to gather data sufficiently definite to furnish a basis for suggestions about hidden and hitherto unknown or undiscovered structural and stratigraphic characters. But the application of it to practical engineering problems is a complicated and difficult matter. And this difficulty is nowise simplified by the occurrence of a drift soil that tends to obscure many of the more delicate features. For example, the later narrow stream gorges marking the stage of extreme regional elevation are completely buried. Only an occasional stream like the Hudson has maintained its course unchanged and has begun excavating the channel again. But even in this case, as will be shown under a separate head, the work of reexcavation is only just begun and the amount yet to be done and the corresponding original depth of the gorge are wholly unknown.

Certain surface features, however, are readable and, considered with due regard for all possible causal factors, give very useful suggestions. From them one obtains clues as to (1) the attitude or relations of the hard and soft beds and the weak zones, (2) the dip and strike of strata, (3) the persistence of a formation, (4) the occurrence of faults, (5) the direction of the chief disturbances, (6) the resistance and durability of local rock types — in short the structural characters of all kinds because differences in the distribution of these characters have given the different topographic forms and geographic areas. They have made the features of the Highlands look different from those of the Catskills, and those of Wallkill valley different from the Croton. Because of the long train of conditions with which these surface features are each involved and the structures that they indicate they become easily the chief factors in preliminary judgment of comparative practicability of rival locations, and are the most reliable guide to direction and character and extent of exploratory investigation for many engineering enterprises.

d **Physiographic zones.** In summarizing the physiographic data it appears that the following belts or zones may be regarded as fairly distinct units:

GEOLOGIC FORMATIONS

Catskill and Oneonta sandstone conglomerates

Sherburne flags

Hamilton and Marcellus shales

Onondaga limestone

Esopus grit

The Helderberg series

Shawangunk conglomerate

Hudson River shales, sandstones and slates

Wappinger limestone

Poughquag quartzite

Storm King granite

The Highlands gneisses



The Catskill mountains

Ashokan reservoir

Hamilton escarpment

Esopus creek
High Falls

Rondout creek
Shawangunk mountains
Wallkill river

Hudson river

New Hamburg
Wappinger creek

Fishkill creek
Newburgh

Breakneck mountain

Storm King mountain

Bull mountain

Crows Nest

Foundry brook

Cold Spring
West Point

Relief map of the region from the Catskill mountains to the Highlands showing the principal physiographic features. (The original model shows also the areal and structural geology.) (Taken from model made in the physiographic laboratory of Columbia University by Messrs Billingsley, Grimes and Baragwanath)

(1) *Coastal plain.* A district underlain by Cretaceous and later rocks and confined to a part of Staten Island and Long Island, not exceeding 400 feet relief. This zone is characterized by dendritic drainage, except a narrow belt on its inner margin which is a longitudinal valley of the "inner lowland" type. Long Island sound occupies the position of this old adjusted valley.

(2) *Piedmont belt.* A district lying between the coastal plain and the Highlands. It is underlain chiefly by crystalline rocks and metamorphosed sediments. Not exceeding 800 feet relief. It is characterized by adjusted drainage obscured only by drift. The ridges and valleys trend northeast and southwest close together and with very little variation on the east side of the Hudson, while on the west side the gentle dips of the Triassic give broader and more unsymmetrical forms with dip slopes and escarpments wholly independent of the opposite side. The zone is essentially transitional between the simple forms of the coastal plain and the complex mountainous character of the Highlands.

(3) *Highlands.* The rugged elevated zone formed by the crystalline gneisses. Reaching elevations of 1600 feet. It is characterized by irregular mountain masses and lofty ridges of a general northeast trend but with many prominent irregularities both of form and of drainage. The valleys are deep and narrow. There are many steep escarpments. It is a mountainous zone in which complex structures and rocks have led to the development of complex forms. The zone forms a sort of barrier 20 miles wide across the Hudson river which exhibits its most zigzag and narrow and gorgelike development in this district.

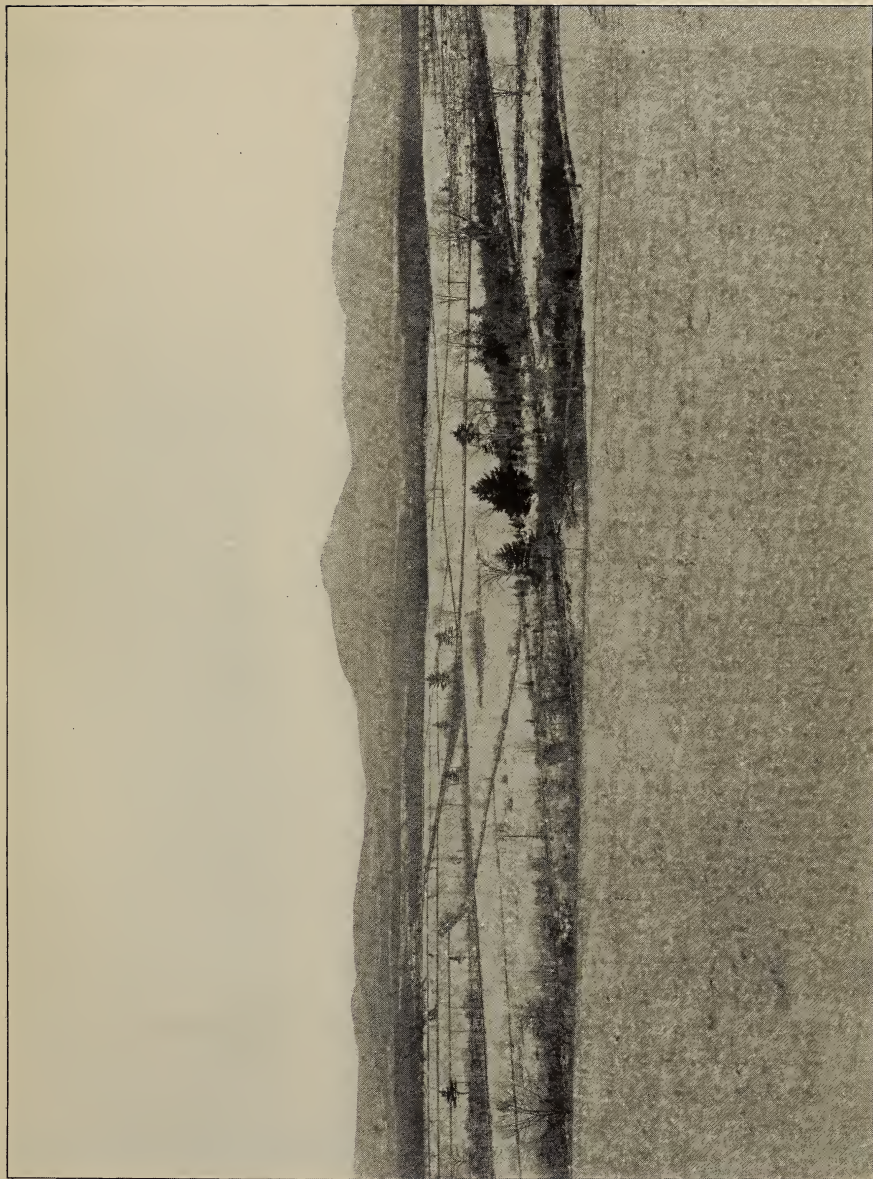
(4) *Appalachian folds.* Characterized by folded Paleozoic rocks north of the Highlands. Reaching elevations of 1500 feet rarely—general relief 400–800 feet. North of the Highlands the relief is much less pronounced. The softer rocks of the early Paleozoic formations permitted the development of a broad valley with almost perfectly adjusted tributaries, most of which on the west side of the Hudson are reversed. The topographic forms give expression to the universal folding and faulting of the formations. It is essentially a transition from the complex mountain zone of the Highlands to the much simpler Catskill area.

(5) *Catskill Monadnock group.* Characterized by undisturbed Paleozoic strata and very strong relief—reaching elevations of 3500 feet. The eastern margin is an escarpment facing the Esopus and Rondout valleys which are adjusted to the gently dipping strata of that side. Over the rest of the district the beds lie so

flat that drainage is essentially dendritic modified slightly by jointing. The great relief of the Catskills is due wholly to erosion of flat but very resistant strata that withstood the destructive erosion of Cretaceous peneplanation and stand as residuary remnants even to the present time. The Catskills are therefore essentially a Monadnock group. In structure they are almost as simple as the higher portions of the cuesta of Long Island, and they hold the same relation to the forms developed by erosion out of the old Paleozoic coastal plain of the interior.

Summary

Physiographically the most complex zone is midway in the region under discussion — i. e. The *Highlands*. This belt is bordered on both sides by less complicated zones of less relief, of more regular topographic forms and less obscure history — the *Piedmont zone* on the south and the *Paleozoic folds* on the north. The outer margins are both simple, essentially eroded coastal plains with strata dipping away from the central belts and on which forms and drainage lines characteristic of such history are developed. These outer zones are the *coastal plain* of Long Island on the south and the *Catskill Monadnock group* on the north. It matters little that they differ in age by almost half of the known geologic column.



A view of the Catskill mountains looking across the Beaverkill basin which is to form a part of Ashokan reservoir

II

GEOLOGIC PROBLEMS OF THE AQUEDUCT

INTRODUCTION

The group of studies assembled in this part are chiefly those that have required considerable exploratory investigation in connection with the proposed Catskill aqueduct and that have furnished new data of a geologic character. In some cases the additional investigations have discovered new and wholly unknown structures or conditions and in all cases the features as now established are much more accurately known than would otherwise have been possible.

The benefits of the studies have been twofold and reciprocal. On the one side the practical planning of the enterprise has constantly required an interpretation of geologic conditions as a guide to locations and methods and on the other the extensive investigations carried on have given an opportunity for practical application of geologic principles under conditions seldom offered and the data secured in additional explorations serve to make the detail of some of these complex features now among the most fully known of their kind. Examples of such cases are (*a*) the series of buried preglacial gorges (as in the Esopus, and Rondout and Walkill and Moodna valleys) and (*b*) the completed geologic cross sections (such as the Rondout valley, the Peekskill valley, Bryn Mawr, etc.) and (*c*) the numerous additions to the knowledge of local rock conditions (such as that at Foundry brook, Rondout creek, Coxing kill, Pagenstechers gorge, Sprout brook, and others).

Almost every locality has its own specific problem and its own peculiar differences of treatment and interpretation of features. Nearly all of the studies here presented came to the attention of the writer and others¹ in the form of definite problems or questions involving an interpretation of geologic factors and an application to some engineering requirement. Some of these questions, as is pointed out more fully in part 1, chapter 2, are (*a*) the location of

¹ Professor James F. Kemp of Columbia University and W. O. Crosby of the Massachusetts Institute of Technology and the writer constituted the regular staff of consulting geologists.

buried channels beneath the drift, (*b*) the character and depth of the drift, (*c*) the kind of bed rock, (*d*) the condition of bed rock for construction and permanence of tunnel, (*e*) the underground water circulation, (*f*) the occurrence of folds and faults, (*g*) the position of weak zones, (*h*) the depth required for substantial conditions, and many other similar problems.

These need not be treated in their original form. Indeed many of them have now ceased to be problems in any real sense, for subsequent provings have made them simple facts, and wholly new questions came to take their places. In some of the larger problems, however, it is believed that a treatment which involves a discussion of the original problem and the method of solving it, together with the data thus secured and the final interpretation of geologic features as now understood or established will be more instructive than a mere enumeration of the collected results.

So far as possible each problem is treated as a unit and fully enough to be understood by itself. But a general knowledge of local geology as outlined in part I is assumed.

CHAPTER I

GENERAL POSITION OF AQUEDUCT LINE

Surface topography constitutes the chief factor in determining the general course of the aqueduct. It is planned to control the water so that it will flow to New York city. There is therefore a gradual descent of aqueduct grade from 510 feet A. T. at Ashokan dam to 295 feet at Hill View reservoir. Wherever the surface of the country is approximately the same as the aqueduct grade for that district it permits of the so called "cut and cover" type of construction which is much cheaper than any other. Therefore, other things being equal, the position that will permit the greatest proportion of cut and cover work would have a decided advantage. So it is possible from any series of good topographic maps to lay out trial lines that are sure to be worthy of consideration. The topographic sheets of the United States Geological Survey and the maps of the New York Geological Survey are of great usefulness in such preliminary work.

But a little field examination shows that there are many other features and conditions that materially modify even comparative cost and are still more important factors in consideration of permanence and safety. Sometimes it is not apparent that a course has any objectionable features till considerable exploratory work has been done. Likewise a serious difficulty at one point may more than counterbalance advantages at some other, so that considerable portions of the line are finally shifted to a better average position. In the course of these preliminary explorations much valuable data have been secured that now relate to points a considerable distance off the present line. The information has, however, been necessary and useful.

One of the cases of this kind where geologic conditions have had an almost controlling influence is involved in the choice of place of crossing of the Hudson river. It has involved a shift of the whole line between the reservoir and the Highlands. Difficulties encountered in finding a crossing of the Esopus also contributed to the argument favoring a shift of the line [*see* map of trial lines west of the Hudson]. One of the points where exploratory work had reached definite results before the more southerly line was finally adopted is near West Hurley. Here wash borings

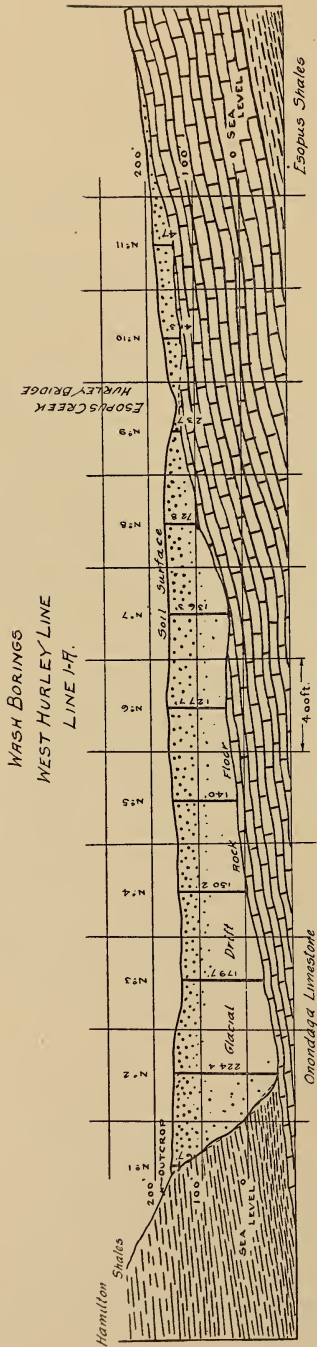


Fig. 7 Geologic cross section of the Esopus valley at West Hurley as indicated by a series of wash borings

were successfully put down through the fine sands and silts of the lower Esopus valley so as to give a fairly acceptable profile of the rock floor [see fig. 7]. Esopus creek in this portion of its course follows the Hamilton shales escarpment which forms a steep border on the west side, while the east border of the valley and floor are formed by the underlying Onondaga limestone. Gentle westerly dips prevail for both formations, so that in the perfect adjustment reached before the glacial invasion a cross section would have shown a typical unsymmetrical valley—one side a gentle dip slope and the other a bluff developed by the undercutting of the stream as it shifted against the edges of the shales.

Results of exploration show that the valley is filled to a depth of more than 200 feet with silts and sands that are essentially overwash and glacial lake deposits. The flat surface further favors this explanation as had been pointed out before any explorations were made. Later observations in that portion of the Rondout valley which is a continuation of this structural feature indicate similar deposits as far south as the new line at Kripplebush, 10 miles away.

In this instance at West Hurley by careful measurement of dips on the Onondaga limestone and the Hamilton shales it was possible to estimate the approximate depth to which the Onondaga floor rock would pass by the time the base of

the escarpment is reached. It was further believed that the covered portion is wholly drift-filled down to the Onondaga. It was easy therefore to estimate the approximate profile and suggest the point of greatest probable depth. The accompanying figure illustrates the form and structure of this valley. Each valley has had in a smaller way a similar study and adjustment of location of line.

The final result is shown on the accompanying map which indicates the course of the aqueduct as now being constructed.

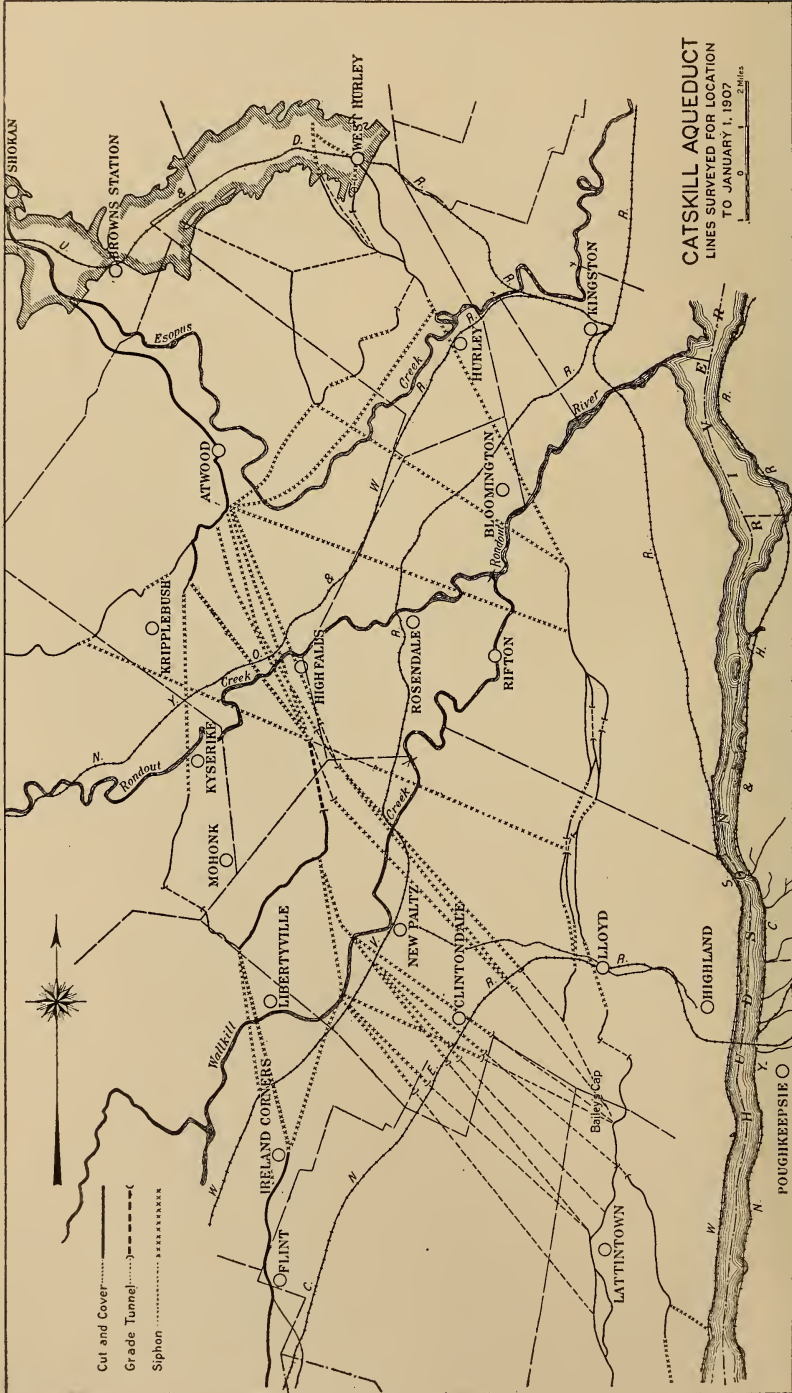


Fig. 8 Location map; showing lines surveyed for possible location and final line selected with its different types of construction — cut and cover, grade tunnel, and pressure tunnels. The line finally chosen passes through Atwood, a little to the west of High Falls and Libertyville, and through Ireland Corners. (By courtesy of the Board of Water Supply)

CHAPTER II

HUDSON RIVER CANYON

This is a special study of the Hudson river gorge¹ based upon explorations by borings at the several proposed crossings. Altogether 226 preliminary borings were made on 14 cross sections. The most important lines of borings are located at seven different points on the Hudson [*see* location map]. Four of them are in the vicinity of New Hamburg, lying not more than a couple of miles north and south of that village, while three others are located within the Highlands. [*See* comparative geologic study in following chapter.] The chief basis of information on all but one of these lines is the wash rig, a contrivance as already pointed out that gives rather incomplete data [*see* Relative Values of Data, pt 1]. On this account it is not possible to give the true bed rock profiles of the river canyon even approximately except at one location, i. e. the Storm King-Breakneck mountain line. An occasional diamond drill hole has been put down on some of the others and this has been done systematically at the Storm King location in a persistent effort to determine the gorge profile and bed rock condition.

The work already done has proven that in the Hudson at least the wash rig borings give wholly unsatisfactory profiles. The holes do not penetrate the boulders and heavy glacial drift that is now known to fill the canyon. The profiles, however, that were drawn from this sort of data have some value. They indicate that bed rock is still lower and that the finer silts extend down to these depths. In some places there is a heavier filling of 400 to 500 feet below them before the rock floor is reached.

Wherever the diamond drill has succeeded in reaching rock the formational identification has been made and the geological cross section is a little more complete. As a matter of fact, however, at almost every locality the structural relations are so complex or so obscure that they are still not fully known. The accompanying profiles and cross sections summarize the mass of accumulated data:

¹ Kemp, Prof. J. F. Buried Channels beneath the Hudson and its Tributaries. *Am. Jour. Sci.* Oct. 1908. 26:301-23. Some of the accompanying descriptions of river crossings follow closely this excellent summary of Hudson river explorations from Professor Kemp.



Fig. 9 Key map showing the locations of lines of wash borings forming the basis of the accompanying cross sections of the Hudson above the Highlands

I Points of exploration¹

a Tuff crossing. This line is a half mile above Peggs point. Wappinger limestone forms the east bank of the river and Hudson river slates the western bank. There seems to be no abnormal structural relation of the formations. All data are from wash borings. The accompanying section gives the results.

b Peggs point line. Peggs point is 2 miles north of New Hamburg. At this location Wappinger limestone forms the east bank and Hudson river slates the west bank of the river as in the previous case. The limestone dips gently westerly while the slates have a variable attitude. This is a normal relation and there is no direct evidence of any great structural break. A large number of wash borings have been made and five diamond drill holes were driven, three of them in the river. None indicate a greater depth than 223 feet, although there is a wide stretch, 1040 feet, not explored by the diamond drill. This space must contain the deeper gorge if one exists here. From the known conditions at the entrance to the Highlands, 10 miles further down stream, where the channel is known to be more than 500 feet deeper, it may be rather confidently asserted that a deeper inner channel does exist at this point.

c New Hamburg line. This line crosses the Hudson from Cedarcliff to the village of New Hamburg. The river is narrow — only 2300 feet. There are no drill borings within the river channel, but there is one on each bank. Both penetrate Wappinger limestone first and then pass into Hudson river slates beneath. How much of a gorge exists here is wholly unknown except in so far as may be judged from the wash boring. There are the same reasons for believing that a gorge exists as those noted for the Peggs point line.

Structurally this line is probably the one of greatest complexity. It is however perfectly clear that the abnormal position of the slates and limestone on the east side of the river is caused by a thrust fault. A similar relation of the slates and limestone on the west side must be due to a like movement, but whether they are separated portions of the same structural unit or of two adjacent ones is not clear, although they are probably distinct

¹ All of these explorations on the Hudson river have been under the direct supervision of Mr William E. Swift, division engineer, in charge of the Hudson River division.

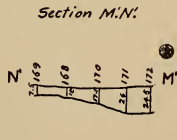
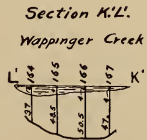
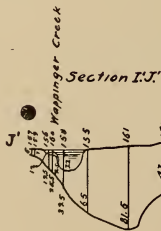
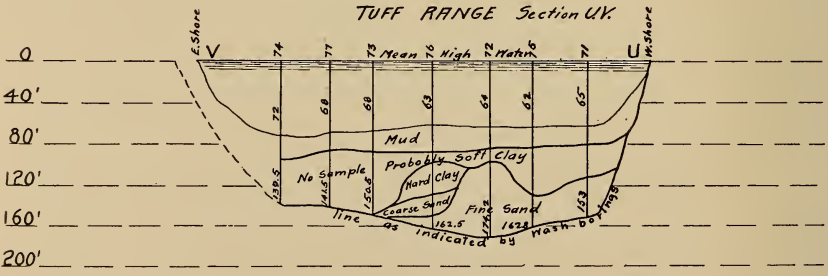
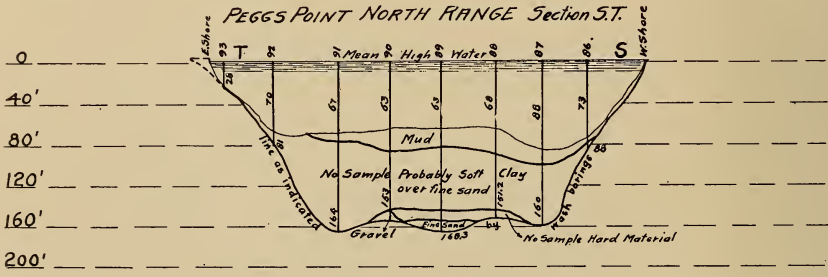
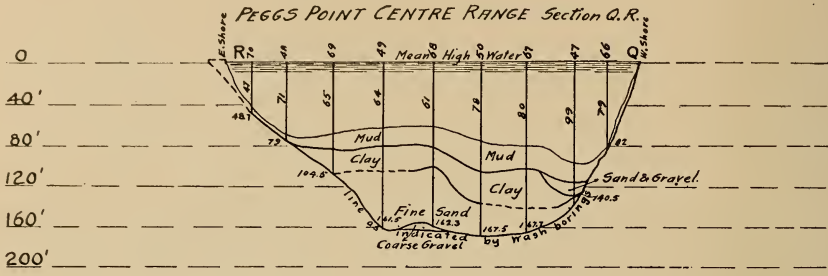


Fig 10 Cross sections of the Hudson river north of New Hamburg and of Wappinger creek based upon wash borings. [For locations see key map, fig. 9]

Five lines of wash borings were followed, and the results of these are indicated in the accompanying figures. A maximum depth of 263.5 feet is shown by these wash borings.

d **Danskammer line.** This line is about a mile south of New Hamburg. Two lines of wash borings were made, reaching a maximum depth of 268.5 feet. In this case slates standing almost vertical form the east bank and limestone dipping gently eastward the west bank of the river. Whether there is a deeper gorge or a more complex structure here is wholly unknown.

Of the three remaining lines, all of which are within the Highlands, that one projected between Storm King mountain on the west and Breakneck ridge on the east has been much the most thoroughly explored. It is known as the Storm King line. The other two have seemed to merit less attention. One crosses the river from Crows Nest mountain to Little Stony point and Bull mountain just north of Cold Spring, and is known as the Little Stony point line. The other crosses at Arden point about a mile south of West Point and Garrison.

e **Arden point line.** Only wash borings were made. A maximum depth indicated by this method is 220 feet. Structurally this location appeared to have disadvantages, and although the evidence as to bed rock conditions is confined to the natural outcrops, there is no doubt but that it has objectionable features of this sort.

The Hudson follows closely the structural control in this portion of its course. These structural elements include the foliation, the bedding of the original sediments, the subsequent shearing zones, and the strike of folds and faults. Crushed and sheared zones are nowhere in the Highlands seen so extensively developed as on the islands and the east bank of the Hudson in this, the central portion of its Highlands course. The river is very narrow, being only 2120 feet on this line.

f **Little Stony point line.** The river here is 2360 feet wide. The rocks on each side are similar and give no clue to possible depths of channel. Less than 200 feet was reached by the lines of wash borings. Three drill borings penetrated the stony or bouldery river filling somewhat deeper — one near the center reaching 322 feet. None, however, reached bed rock.

g **Storm King crossing.** Extensive exploratory work has been carried on at this point, both on the banks and in the river. Wash borings as usual have given poor results. Two diamond drill holes were run at an angle toward and beneath the margins of the

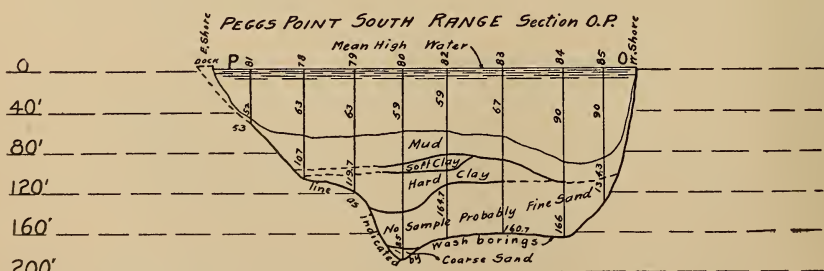
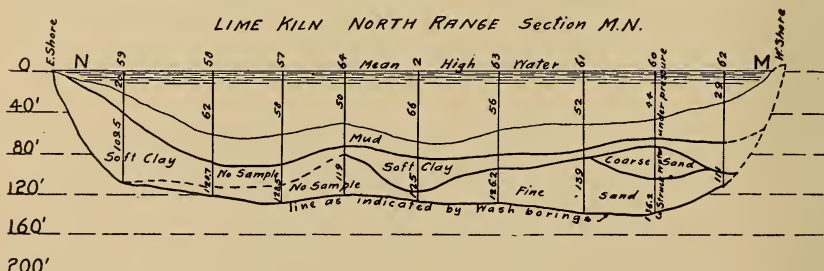
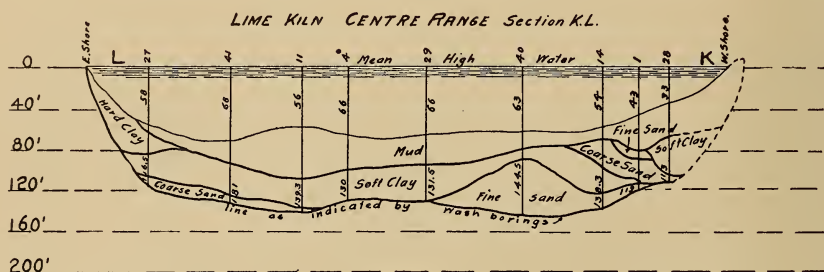
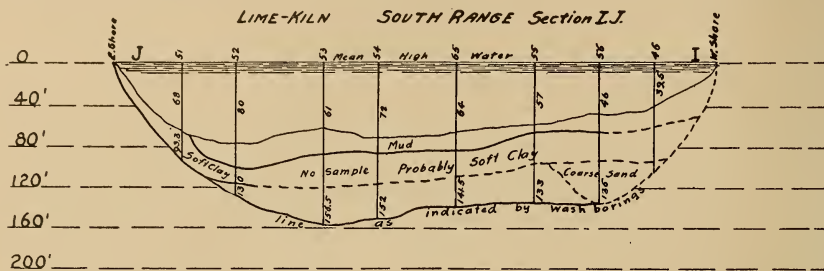


Fig. 11 Cross sections of the Hudson river near New Hamburg based on wash borings [For locations see key map, fig 9]

river, and in addition a working shaft suitable for permanent use has been started on each side of the river. These have thoroughly explored the rock character to a depth of about 800 feet. It has proven to be of constant type, a gneissoid granite, affected by moderate amount of jointing, shear movements and occasional dike intrusion. The two sides are alike, the rock in depth is comparatively free from water, nearly all coming from the adjacent surface drainage.

Persistent efforts have been made to use the drill in the river to explore the rock channel, but with meager results. The difficulties to be overcome in drilling in this tidal river to the necessary depth are probably greater than have even been encountered in any similar undertaking. The disturbance presented by the current, the tide, the depth of water, the drift filling above the rock channel, and the traffic in the river are a constant menace. The complex character of drift filling in this gorge, especially the occasional heavy bouldery structure, makes it necessary to reduce the size and recase the holes repeatedly. But in this regard the work has suffered less actual loss than by the menace of river traffic. Several times after the greatest efforts had been put forth in pushing the drills deep into the gorge a helpless or unmanageable or carelessly guided steamer or scow has wrecked the work. In this way some of the most critical locations have been lost together with many months of labor.

The results are shown on the accompanying drawings.

It is worth noting that of those holes located far out in the river channel only two have reached bed rock. Even these two have penetrated the rock so little distance that there might be still some doubt of permanent bed rock. The fact, however, that the rock found is of the right type, i. e. like the walls of the gorge, leads to the conclusion that the bottom was actually penetrated. Neither of these holes are in the middle of the river, and, although the maximum depth of 608 feet was reached by one of them, the central portion of the buried channel proves to be still deeper. One hole located near the middle was able to penetrate to a depth of 626 feet without striking bed rock. But it was finally lost. The latest results are from a boring that has reached a total depth¹ (January 1, 1910) of 703 feet, the last 8 feet of which was believed by the drillers may be in bed rock. All above is drift and silt.

¹ Subsequent exploration has proven that the bottom of the old channel lies still deeper. This boring has been pushed to a depth of 751 feet without yet touching bed rock (Oct. 8, 1910).

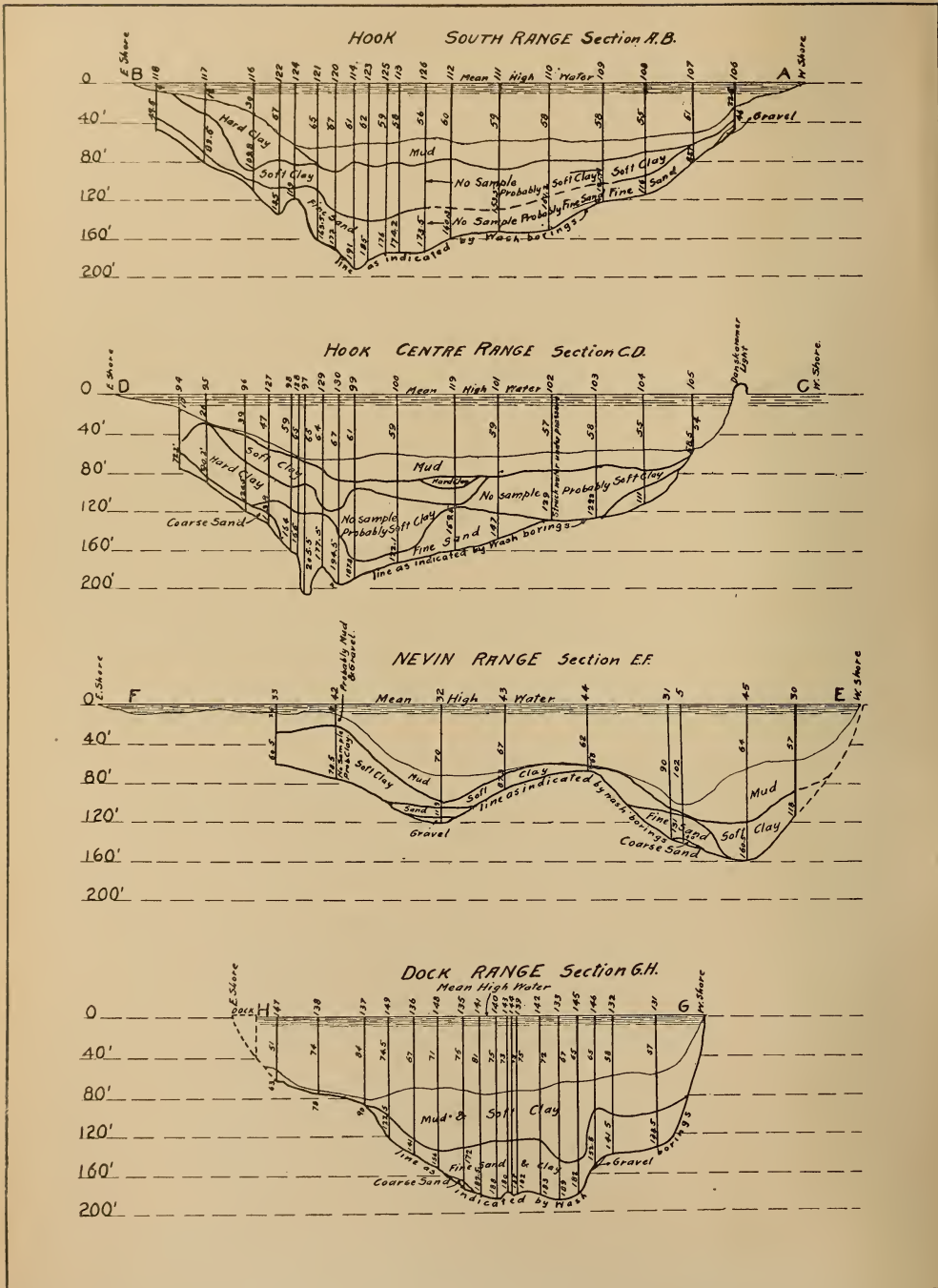
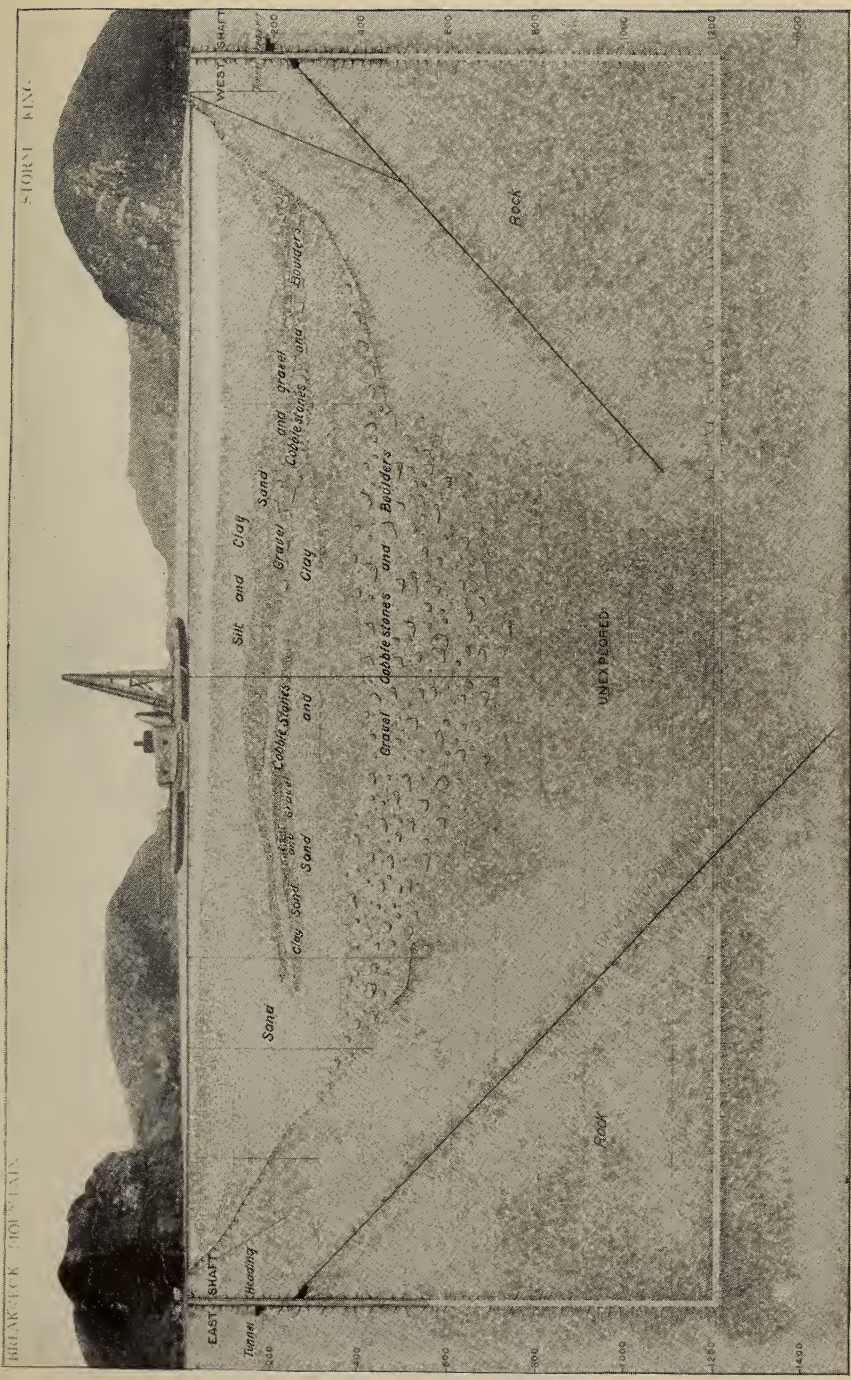


Fig. 12 Cross sections of the Hudson river at four points between Danskammer Light and New Hamburg [see key map, fig. 9, for locations]



A composite diagrammatic cross section of the Hudson gorge at the Storm King showing the method of making the vertical borings, the direction of the first two inclined borings, the positions of the shafts and the extent of explorations. (Adapted from drawings of the Board of Water Supply)

2 Discussion

The present facts therefore indicate that the buried Hudson channel is more than 700 feet deep between Storm King and Breakneck ridge. Furthermore this is more than twice as great depth as has been found (so far as yet tested) at any other point either above or below this place. Although data of this kind are scarce yet there are two other borings that have given surprising results—(a) at Peggs point and (b) the Pennsylvania borings at New York city.

Peggs point. At this place, where studies were made for a possible crossing, a hole 700 feet from shore struck rock at 223 feet and the unknown space or interval within which it is possible for a channel to lie is less than 1040 feet wide. This is about 10 miles above the Storm King crossing and in much softer rock (Hudson River slates). Yet the Storm King gorge in granite is deeper than that (deeper than 223 feet) for a width of nearly 2500 feet. Of course, there may be, and probably there is, a much deeper channel at Peggs point within the 1040 feet unexplored space. But even so there is a remarkable discrepancy in width of gorge at these two points that must be accounted for in some other way than simple stream erosion.

The Pennsylvania borings opposite 33d st., New York city. The data gathered by the Engineers of the Pennsylvania Tunnel Company in their explorations for tunnel from 33d street, Manhattan, to Jersey City, have recently been made public. There are six holes into rock. Their positions and depth to rock bottom are given below:

a 800' from New York bulkhead 190' to bed rock = aplite

b 1000' from New York bulkhead 290' to bed rock = hornblende schist

c 2180' from New York bulkhead 300' to bed rock = chloritic and serpentinous rock.

d 2350' from New York bulkhead 260' (?) to probable boulder = jasper breccia

e 3300' from New York bulkhead 270' to bed rock = arkose sandstone

f 13700' from New York bulkhead 225' to rock = brown sandstone

There are other shallower borings on both sides of the river. Those on the Manhattan side are represented by several different facies of Manhattan mica schist and granite and pegmatite in-

trusives, while the New Jersey side is represented by different varieties of arkose and gray and brown sandstone belonging to the Newark series.

It should be noted that although only one hole marks rock bottom as low as 300' (that one situated 2180' from the New York bulkhead about the middle of the river), yet there is at least a 1100 foot space on each side which is essentially unexplored, and within one of these spaces there may be a deeper gorge.

The cores taken from the east side of this middle zone belong to facies of the Manhattan schist formation, while those on the west side belong to the Newark series. The middle one, however, is essentially a soapstone or serpentine and may be a continuation of the Hoboken serpentine belt. In any case, it belongs in age to the older series of formations.

It is certain that here again, 50 miles below Storm King locality, a very deep gorge, if one exists, must be comparatively narrow.

Submarine channel. It is worth noting in this same connection that a submerged gorge has been mapped by the Coast and Geodetic Survey on the continental shelf from the vicinity of Sandy Hook to the deep sea margin, a distance of more than a hundred miles. This is interpreted by Spencer¹ and others with apparently sound argument as the lower portion of the old preglacial Hudson gorgé formed during an epoch of great continental elevation. The outer portion of this submerged gorge is very deep. That section near shore is shallow and obscure. It has been assumed that this obscurity and shallowness is due to offshore and river deposition, filling the channel with silt. No better explanation is yet forthcoming. But even here the width of the submerged gorge is suggestive. In very much softer sediments than any encountered in its whole course on present land, and in a part of its course from 50 to 100 miles below the other sections, the river has cut a gorge only 4000 feet wide at top and 2000 feet deep within a broader valley 5 miles wide. In its deepest known part the proportions are 10,000 feet in width at top to 3800 feet in depth.

From this it would appear that the inner gorge type of development is characteristic of the Hudson, and that it was originally an exceedingly narrow one compared to the present river width, indicating rapid erosion during a brief and comparatively recent epoch. This submerged continental margin condition is favorable to the

¹ Spencer, J. W. The Submerged Great Canyon of the Hudson River. *Am. Jour. Sci.* 1905, v. 19.

Plate 15



The enlargement of the Hudson river known as Newburgh bay as seen from the northerly slope of Storm King mountain. This shows the gathering ground of the tongue of glacial ice that enlarged and overdeepened the Hudson gorge at the Gateway. (Photograph by Board of Water Supply)

assumption that there are narrower, still deeper channels within the unexplored spaces both at New York city and at Peggs point.

The only known exception and the one really surprising section is the Storm King crossing. It is too wide, considering the profiles at Peggs point and at New York city for simple normal stream erosion. That is clear enough. But a still more difficult question is whether it is also too deep. It is much deeper than any known section above or below for a distance of 50 miles.

There appears to be only one satisfactory explanation of this abnormal width of the deeper section and that is by glacial erosion. Just above Storm King is the wide bay opposite Cornwall and Newburgh. The few glacial scratches observed trend about $s. 15^{\circ} e.$ The ice therefore moved to the east of south, and it is noted that the course of the river is about the same. The northern front of Storm King mountain is steep and trends east and west while the northern front of Breakneck mountain trends southwest. It would appear therefore that these slightly converging mountain fronts served as sort of a funnel into which the ice was forced from the wide gathering ground immediately above, and through which there may have been a tongue or stream of ice of more than average power and efficiency moving almost in direct line of the present course of the river. It is reasonable to expect that these conditions would favor more than average glacial erosion.

3 Storm King-Breakneck mountain profile

It is practically impossible to draw a complete profile for the Hudson river gorge at any point in its lower course. Even at Storm King mountain or New York city or at Peggs point, at each of which places considerable exploratory work has been done, only the broadest features are known. Nevertheless, several things have been proven and they are worth considering in this question. They may be summarized as follows:

a If there is a very deep gorge at Peggs point (deeper than 250 feet) it can not be over 1000 feet wide.

b If there is a very deep gorge at New York city (deeper than 300 feet) it can not be over 1200 feet wide.

c At Storm King, located between the other two and in harder rock than either of them, a gorge at least 400 feet deep is proven to have a width of more than 1500 feet.

It is certain that simple stream erosion could not account for such a difference of cross section. There is no doubt but that en-



Fig. 13 Comparative sections of the Hudson gorge—at Peggs point, at Storm King and at 32d street, New York city—drawn to the same scale to show the remarkable size of the Storm King section below 300 feet

larging by ice so far as widening is concerned is practically proven. It may also be overdeepened, by which is meant that it may have been gouged out deeper than could have been done by a stream of water alone.

If ice action then be granted, the profile ought to be and probably is essentially an ice valley profile, i. e. of a more or less U-shape, rather than of typical stream erosion form. It is certain also in this case, if glacial overdeepening is admitted, that there can be no stream notch in the bottom of it. The significance of this lies in the probability that the floor is approximately the same level on a considerable portion of the bottom, so that when once the margin of this floor is touched the gorge as a whole is thereby determined for depth.

After plotting the borings data and relying upon the factors that seem to be most firmly established, it appears that the following statements are as definite as the facts will warrant:

a The average slope of the Storm King side of the valley above river level is nearly 38° , and this is in several steps or sections of steeper and flatter slopes. The Breakneck side is about the same.

b The average slope of the Breakneck side of the gorge below present water level (the side on which alone there are enough data to plot a fairly good curve) does not vary much from this same value [*see* accompanying profile]. And it is also in steeper and gentler slopes, apparently a series of U-shaped forms set one inside the other, each inner one deeper than the next outer one. Each successive inner step is approximately 300 feet deeper than the last and 1000 feet narrower.

It is certain that this sort of profile is not as simple as at first appears. The surprising feature is the close approximation of the slopes above and below present river level. In view of the fact that glacial widening has been practically proven, as shown before, not much importance can be attached to this uniformity or similarity of slope. Ordinarily such a persistence of slope would be taken to indicate simple stream origin, but having abandoned that hypothesis, the value of the angle as a factor in estimating probable total depth is lost. In short, one can not assume that the deepest point is indicated by the intersection of the slopes of the two sides.

But there is one feature that is at least suggestive. That is the uniformity of the succession of steps and slopes. It was noted above that each successive inner one is about 300 feet deeper and 1000 feet narrower. If this uniformity and proportion is main-

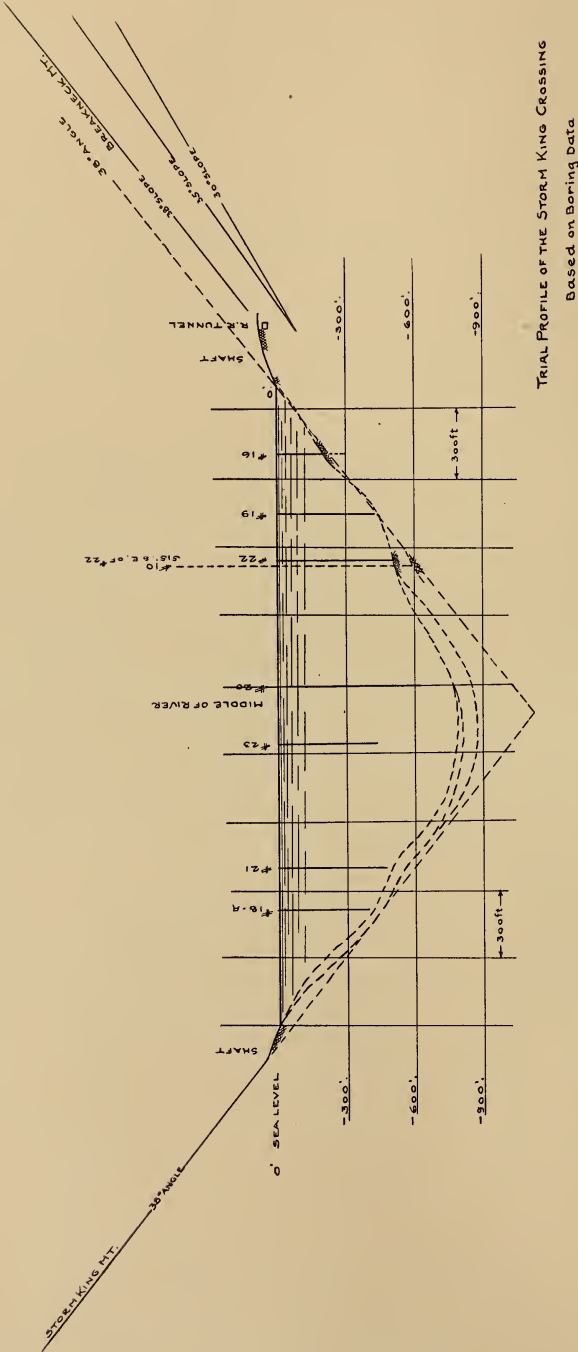


Fig. 14 A study of the Hudson gorge profile showing location and depths of the principal borings. The tendency to U-shaped forms, one within the other, is believed to be indicated by the borings on the Breakneck mountain side and give a suggestion of the probable depth of the innermost form.

tained for the next inner one — inside of holes no. 10 and no. 22 — there would be room for only one more and its approximate depth would lie somewhere between 800 feet and 900 feet below tide.

Recent drilling has shown a marked difference between holes no. 10 and no. 22. Hole no. 10 located 500 feet southeast of no. 22 is nearly 100 feet deeper. Since no. 10 is nearly straight down stream this discrepancy is disturbing. But if one considers the distance of each from the east bank it is noted that no. 10 is 900 feet out and no. 22 is 800 feet. Hole no. 10 is thus about 100 feet nearer the middle of the stream and allowing for this additional distance according to the profile as known it ought to be at least 70 feet deeper than no. 22. This corrected difference then of 30 feet does not seem to be of much importance.

Summary. Everywhere in its lower course the Hudson exhibits the character of a narrow gorge, sometimes of a gorge within a gorge, most of which is either submerged or buried several hundred feet.

Depths of 200 to 300 feet are average and for the last 60 miles of its course represent widths of 1000 to 3000 feet.

Greater depths are believed to be maintained continuously within a narrower inner notch, but of this there is no conclusive proof and very little evidence outside of a few Storm King borings.

The Storm King-Breakneck notch is over 751 feet deep. But it is abnormal at least in width and probably also in depth, due to ice erosion.

The conditions indicate (*a*) rapid stream erosion while the continent stood much higher than now, (*b*) glaciation which enlarged the gorge in at least a few places and filled it with rock debris and later with mud during submergence, (*c*) finally an emergence with minor oscillations and erosion to the present time.

4 Origin of the present course of the Hudson

The course of the Hudson is in most respects no more abnormal than that of the Susquehanna. Both flow across mountain ridges in such manner as to indicate their superimposed character. Both date back to the Cretaceous peneplain. But the striking feature of the Hudson is its straight course. As Hobbs and others have pointed out, the river is abnormally straight for more than 200 miles — and this in spite of the fact that it crosses the bedding and other structures of the country rock at nearly all points at an

oblique angle. Such conditions are especially notable south of the Highlands where the Hudson cuts at a low angle across the ends of a succession of complex folds of the crystalline metamorphics for 30 miles to New York city. But this is true only of the east side of the river. The west bank is an almost unbroken uniform escarpment of the Palisade diabase intruded sheet underlain by Newark sandstones, which if laid down upon a pretty well planed Pretriassic surface might easily control the Hudson, and which would not differ from its present course.

The most evident exception to this is the course of the river from Hoboken to Staten Island. Instead of following the line of contact between the crystallines and Triassic formations, the river cuts through the crystallines leaving large masses of serpentine and associated schist on the west side. This together with the behavior of the river in cutting across the strike farther north near the Highlands is believed to strongly favor the fault theory of location especially south of the Highlands. The same conditions would be favorable to the development of a narrow gorge and perhaps a very deep one rapidly eroded along the crush zone of the fault.

From the northern entrance to the Highlands to Haverstraw bay, where the Palisades are reached, the stream course is not by any means straight, but shifts from longitudinal structure to cross structure alternately in a zigzag manner. North of the Highlands the course is more direct again. On the whole the present explorations have added little to the facts bearing upon this question. Faults crossing the river are common and easily recognized. Occasionally one appears to pass into the river gorge at a very small angle and not reappear. In a few places, especially in the Highlands, the course does not seem to be consistent with the hypothesis of a large fault line. It is to be expected that further work at the Hudson river crossing will add materially to the facts relating to the structures within the gorge.

CHAPTER III

GEOLOGICAL CONDITIONS AFFECTING THE HUDSON RIVER CROSSING

General statement

This is essentially a study of the geologic features and conditions shown by exploration to have an important influence upon the choice of river crossing for the aqueduct. In the beginning it was possible to consider that any point between Poughkeepsie and New York might furnish a crossing. The early preliminary investigations showed that it would be desirable to cross either above or within the Highlands and subsequent exploratory work throws light on different possible locations in these regions. Fourteen different lines were tested by wash borings. Later some of these were tested by diamond drill. As data accumulated it was possible to eliminate many of the trial lines and the more detailed and critical studies became confined to a few important possible crossings.

In making a comparison of them as to geological environment it is evident that they fall into two distinct groups¹ [see fig. 15]. One, that may be designated the "New Hamburg" group is represented by the "Peggs point," "New Hamburg," and "Danskammer" lines and is characterized by a series of much folded, faulted and crushed sedimentary rocks, chiefly slates, limestones and quartzites. The other, that may be called the Highlands group, is represented by the "Storm King," "Little Stony point," and the "Arden point" lines and is characterized by crystalline metamorphic and igneous rock of a much older series.

A judgment as to the most desirable crossing involves the selection of one of these groups chiefly upon general geologic features, and finally a selection of a particular line upon minor differences of materials or structure.

In the first place it seems necessary to consider, for each group,

¹ There have been other suggestions for crossing the Hudson river, farther upstream and farther down than these—one being at New York city—but none have had sufficient claim to attention to encourage much detailed work or so careful consideration as those here discussed.

A shift of position of the Hudson river crossing involved a corresponding shift of a large section of the northern aqueduct line. The first choice of location occasioned a shift southward of all that portion between Ashokan reservoir and the Hudson.

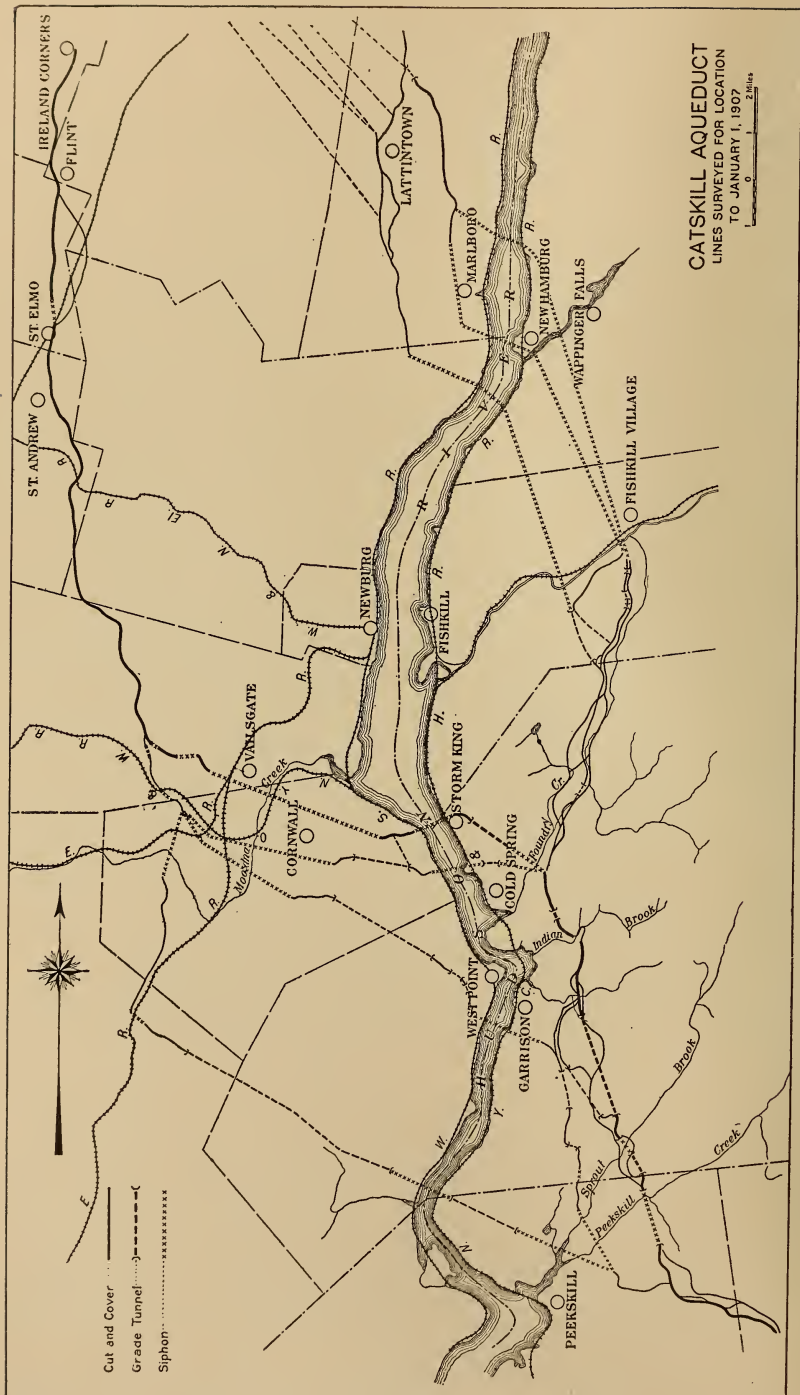


Fig. 15 Outline map showing alternative lines studied as possible crossings of the Hudson river

the whole length of pressure tunnels whose position would be modified by a shifting of river crossing. This is because the aqueduct will approach the Hudson with nearly 400 feet head—i. e. 400 feet above river level or with an equivalent pressure. For this reason it is considered necessary to plan a rock pressure tunnel beneath the river which can deliver the water at nearly the same elevation again on the east side.

Thus any one of the "New Hamburg group" involves a continuous pressure tunnel reaching from the margin of Marlboro mountain to Fishkill range, a distance of approximately seven miles, while any of the "Highlands group" permits the substitution of two more or less separate siphon tunnels (Moodna creek and Hudson river) of considerably less combined total length.

A reliable conclusion as to the choice of crossing is probably best reached through a comprehensive understanding of the geologic development of the region together with a consideration of specific local conditions. With this end in view a condensed outline of geologic history, so far as it bears upon the questions at issue, is inserted. But for a more comprehensive discussion of these matters the reader is referred to the explanatory chapter of part I.

Geology

This particular locality, including as it does the Highlands of the Hudson and the district lying along its northern border, is one of the most complicated stratigraphically and structurally to be found in the entire region. The strata represented include more than half the total geologic scale reaching from the oldest sediments following the Archean up to and including a part of the Devonian series [*see* pt I]. The rock types include granites, diorites, gneisses, schists, marbles, serpentines, slates, quartzites, sandstones, limestones, shales, and, less extensively, other varieties. And the region bears the evidence of no less than three periods of mountain-making disturbances, each in its turn adding to the succession of foldings, faultings and unconformities.

The oldest formation is a crystalline gneiss—a characteristic rock of the Highlands. It represents an ancient sediment that has been completely recrystallized during some of the earlier mountain-making period. It is older than the Cambrian. Interbedded with it to a limited extent are quartzite beds, ancient limestones (now usually serpentinous in character) and schistose beds; and in it are many igneous injections, mostly granites of various types. All

these igneous injections are therefore younger than the gneiss and are very large and abundant in certain cases. The granite of Storm King, Crows Nest and Breakneck ridge belongs to this type.

Following the sedimentary cycle represented by the above series, and perhaps others not now preserved, the region was folded into a mountain range, the series was extensively metamorphosed and passed through a long period of erosion during which it was again reduced to sea level position and began to accumulate a new series of sediments.

The lowest beds occurring upon this foundation are sandstones, now changed into quartzite. In places they are conglomeritic, and may now be seen projecting into the valleys along the Highland border. This formation is of Cambric age, and is from 200 to 600 feet thick in favored places. It forms an almost continuous belt along the north side of the Highlands except where cut out by faulting, and extends with similar breaks beneath the later sediments northward. This quartzite is known as the "Poughquag."

Upon the quartzite of this series there was developed a succession of limestone beds at least 900 to 1000 feet in thickness. This formation is known as the "Wappinger" and includes some beds that are of Cambric but for the most part of Ordovician age.

The final member of this series is a shale and shaly sandstone in places changed to slate. It is quite variable in actual character and has a great thickness, never yet successfully estimated, but probably several thousand feet. This is the so called "Hudson River slate" series. In this region they are of Ordovician age.

This is the succession which the proposed Hudson river line has to penetrate in a pressure tunnel. Later Silurian and Devonian strata lie in the immediate vicinity of this alternative line, but add no complication to the problem as it now stands. Therefore no other formations need be considered except the glacial drift. This covers almost every rock surface and is deeply accumulated in some places, notably in the narrow gorges and valleys, obscuring the finer original topographic lines.

A summary of the history of the formations chiefly involved in this problem with a suggestion of later erosion activities may be tabulated as follows:

Cenozoic	{	Glaciation
		Reelevation
		Erosion (interrupted)
		Elevation (rejuvenation)

Mesozoic	{ Erosion to peneplain .....Unconformity A long interval including two mountain-making epochs and at least one period of general sedimentation
Paleozoic	
	{ Ordovician { Hudson River slates Cambrian { Wappinger limestone Poughquag quartzite .....Unconformity A long interval including mountain folding, igneous injection, erosion, and perhaps other sedimentations
Proterozoic	
	{ The metamorphosed schists, limestones, quartzites etc., together with accompanying intruded igneous masses — forming the basal gneisses of the High- lands

The evidence of such succession and history gathered from the scattered outcrops of rock in the immediate area, is nowhere better shown than in the field covered by this investigation.

Structure

When such outcrops as are known are plotted and organized, several important facts become clear.

1 The folds run with remarkable persistence northeast and southwest.

2 The succession in many places is not normal. Often a whole formation or even two of them are missing and formations that should be separated are brought side by side. Faulting therefore is prevalent and the occurrences show that these large fault lines usually run northeast and southwest.

3 A consideration of the dips of the strata shows that most of the folds are overturned as if pushed by some general movement from the southeast.

4 This same movement causes the faulting to be largely of the overthrust type, and in some cases the lateral displacement attained in this way may possibly be several thousand feet.

5 Isolated "islands" of the older rock formation appear out in the later sedimentary area. They all seem to belong to prolongation of the ranges of the Highlands and their abundance undoubt-

edly complicates the underground structure throughout a considerable belt.

6 The Highlands area terminates in a serrate margin which, in the latest thrust movements from the southeast, must have created very unequal distribution of stresses within the slate-limestone region to the north causing additional cross folding and faulting. For the most part these can be traced only a short distance before losing their identity.

In a mountain folding movement, the uppermost rocks are most broken and displaced or crushed while those of greater depth may be bent or uniformly folded or even recrystallized. It would appear that this latter was the condition of the Highlands rock series during its earlier history. And even in the latest movements its lines appear to be less radically disturbed than the slates and limestones to the north. Most of the disturbances that invite serious consideration belong to the latest period of these mountain-making upheavals.

Comparison of routes

1 **New Hamburg group.** This group of crossings is in the later sedimentary series. Hudson River slates and Wappinger limestone are the chief formations. But within the southern third of the tunnel, at least, the underlying Cambric quartzite and the older Highland gneiss would be cut—the quartzite possibly three times. The succession therefore will be of considerable complexity as a whole.

All of the formations involved are thrown into very steep dips at most places and are consequently liable to rapid and unexpected changes—some of which probably do not show at the surface.

There are several fault lines belonging to the major northeast and southwest series to be crossed by such a tunnel—one of them in each case being met at considerable depth and beneath or adjacent to the river. These faults besides being the weakest zones of rock as a rule, are in addition the most unstable in any possible future earth movements. Although there is no evidence of recent displacement along these lines, still such a thing is always possible and recent serious effects of this kind on the Pacific coast suggest caution. It is manifestly advisable, if possible, from every standpoint to avoid crossing several of them.

In the field there are numerous springs of very large flow along many of the limestone borders. The concentration of them to these situations in addition to the occurrence of an occasional sink-

hole, leads to the conclusion that they are more intimately dependent upon the limestone structure for their existence than upon the glacial drift or any superficial factor. Their abundant flow, sometimes on high ground, indicates rather extensive structural connections and this is believed to be the limestone bed itself and that such flows would be encountered also in depth. The occurrence of sinkholes suggest also possible solution channels and cavities and distant outlets. The types of rock to be encountered on the lines represented by this group are easily workable. Among them all the Hudson River slates is probably the most satisfactory from any standpoint. It is generally easy to penetrate and has a capacity for healing its own fractures. For this reason it can be considered good ground, tight and safe. But a considerable distance of the tunnel can not be kept in slate—perhaps even more of it than can be proven from surface observations. The other formations are considerably less satisfactory. The limestones are in places shattered and are liable to abundant flow of water. The quartzite is extremely hard, as difficult to penetrate as granite, and where crossed by the faults is probably not healed at all, while the gneiss is doubtless of similar character to that of the Highlands crossings to be discussed later.

Only minor modifications result from a choice of the individual crossing, whether "Peggs point," "New Hamburg," or "Danskammer." In one of them, New Hamburg, it would appear possible to cross the actual river section wholly in slates. This seems to be the reasonable conclusion from the diamond drill boring at Cedar Cliff. But even that line necessitates crossing at least two fault contact lines immediately at the east bank and beneath Wappinger creek at depths not immensely less than that below the river itself and both wholly within the range of influence of the river waters. It would appear therefore that the situation is not materially altered in the present discussion, no matter which particular crossing of this group is considered.

2 The Highlands group [*see* cross section]. In this group of crossings there are two separate features to consider. (*a*) the Moodna creek valley which these lines all cross, and (*b*) the Hudson river itself. Their characteristics are as follows:

a Moodna creek [*see* separate Moodna creek discussion]. So far as known Moodna creek can be crossed almost wholly in slate. It is possible that the underlying limestone may come near enough to the rock floor of the valley to be penetrated but there is little

direct evidence of it. The ancient valley is deep and probably marks a line of displacements which can not be avoided, no matter what route is chosen. The fault contact at the border of the Highlands is not expected to prove troublesome as it seems very tight at the exposures seen. The buried granite ridge (a continuation of Snake hill) which underlies the western end is now known to come within the limits of the tunnel and adds one more complication.

Except for the fact that the ancient Moodna valley is deep and filled with heavy drift that is unusually difficult to prospect, there would seem to be no source of special trouble. It has no lines of weakness that are not also present in the more northerly districts and the tunnel has chances of crossing them under more advantageous conditions without so much complication with the limestone series as characterizes the New Hamburg group.

b Hudson river. Among the Highlands group of crossings there is considerable difference of structure dependent upon the exact location of the crossing. The conditions that prevail may be summarized as follows:

(1) **Storm King location.** This is wholly in massive and gneissoid granite. The rock is the most massive and substantial body of uniform type found in the Highlands. The course of the river indicates some weakness in that direction. This weakness may be some minor crushed zone or even the jointing alone that prevails throughout the exposed cliffs. But there is no direct evidence of faulting, cutting the line and such crushing as may be encountered is believed to have originated at such depth and under such conditions as to cause no large disturbance. The freedom of this formation from all bedding structures and natural courses of underground water circulation on a large scale is an additional factor. There is absolutely no other place, within the region, where the Hudson river can be crossed from grade to grade in good ground of a single type with so great probability of avoiding all large lines of displacement.

(2) **Little Stony point location.** The conditions that prevail at this point are similar to those that characterize the Storm King line. The only known difference is in the considerably more shattered condition of the granite, especially on the west shore at Crows Nest. It is estimated that this crossing is less favorable by reason of just this poorer condition of the rock and the somewhat greater yielding to regional disturbances that it seems to indicate.

(3) **Arden point or West Point location.** On this line the river would be crossed in the gneiss series proper instead of in granite.



The Storm King — Breakneck mountain gateway to the Highlands as seen looking north from West Point. Two of the proposed crossings lie in this gap — the Storm King line reaching to Breakneck, the rugged mountain on the east side, and the Little Stony Point line which crosses from Crows Nest on the west to Little Stony Point, the small low point on the east side. (Photograph by Board of Water Supply)

It is largely an ancient stratified series much metamorphosed containing belts of interbedded limestones, quartzites, and schists, in addition to the more substantial feldspathic gneiss. The eastern bank of the river bears also abundant evidence of extensive crushing and shearing and is believed to indicate a displacement in this zone. For these reasons the West Point crossing is considered an unfavorable route compared to either of the others of the Highlands group.

Summary. In a comparison of the geologic features that are of most importance in contrasting the possible routes for the Hudson river crossing the following points are considered of most importance.

1 The New Hamburg group of crossings involves (*a*) the longest tunnel, (*b*) the more complicated structures, (*c*) the greatest number of known faults, crush zones, and related disturbances, (*d*) the more variable series of rock types to be penetrated, (*e*) the greater tendency to encounter heavy underground water circulation, (*f*) the greater probable susceptibility to disturbance from future earth movements, and (*g*) the greater number of uncertainties of rock relations.

2 In contrast the Highlands group admits of (*a*) shorter total tunnel length, (*b*) the most profound fault lines of the district are crossed either in high ground or are avoided or, because of the rocks involved, promise the least possible trouble, (*c*) the Hudson river itself can be crossed in a single formation with probability of avoiding lines of largest structural weakness confining the greatest pressures and deepest tunnel work within the most uniform and substantial rock of the whole region.

There are, of course, many unknown or only partially known features obscured beneath the covering of drift or lying beneath the river itself; but, however many there may be, it is not believed that they can materially change the general situation. The major characteristics are so well marked that any addition to those already known would in all probability increase the difficulties of the New Hamburg group of routes at least as much as and perhaps more than those of the Highlands group.

In view of the above facts and inferences the judgment has been in favor of the Highlands group of crossings as the more defensible on geologic grounds as a route for the aqueduct line. Furthermore, in accord with the preferences already noted, the Storm King location is regarded as the most likely to give satisfactory results.

Quality and condition of rock

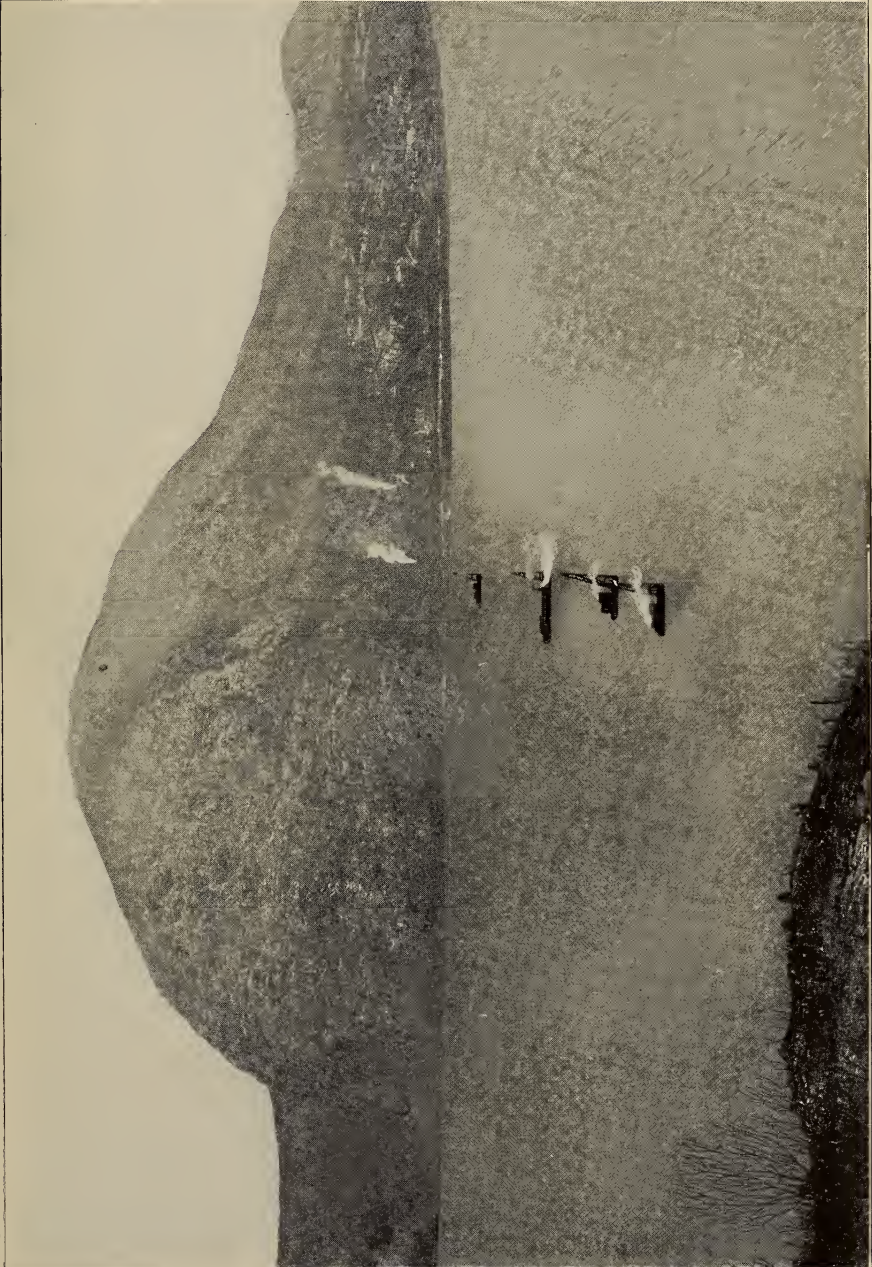
The rock of Storm King mountain and of Breakneck ridge at the Hudson river crossing is a very hard granite with a gneissoid structure of variable prominence. The color varies from grayish to light reddish and the structure is always coarse passing into pegmatite facies that occur as stringers or irregular veinlets. The grayish facies is of slightly finer grain and more gneissoid. Those portions that have been sheared are still darker. There are many joints at the surface running at various angles and an occasional slickensided surface. The mass is cut by several dikes of more basic rock (diorite) of widths varying from a few inches to 8 feet. These dikes are somewhat more closely jointed than the granite and consequently a little more readily attacked by the weather. But where protected they are equally substantial for underground work.

The chief variation from this condition is where crushing or shearing has induced metamorphic changes. Wherever bed rock has been reached at this point and to such depths as workings have penetrated the rock is of this type.

The work includes (*a*) four inclined drill holes from the river margin — two starting from the surface and two from chambers set off from shafts at a starting depth of about 200 feet, (*b*) several vertical holes in the river itself, and (*c*) two large working shafts 20 x 20, one on either side of the river.

These give all the data¹ known as to the condition at depth. From them it is apparent that crushing and shearing have been prominent. Many splendid specimens of crush breccia are thrown on the shaft dump. But its present condition at the depth involved is sound and durable. The fractures are rehealed. There has been a recombination of constituents giving a new matrix of complex silicates among which epidote is the most characteristic, while simple decay is of little consequence. For strength and permanence the conditions could not well be improved. There is no reason to apprehend any change for the worse for the reason that the same tendencies must prevail at that depth throughout. It would appear therefore that faulting movements, or the existence of a fault zone of importance can not become a serious obstruction, because of the tendency to

¹ Since this paragraph was written four inclined diamond drill borings have been made from chambers at depths of about 200 feet in the shafts. These have now penetrated the whole distance beneath the Hudson with very satisfactory results.



Storm King mountain, and the Hudson river from Breakneck mountain showing the location of the proposed pressure tunnel by the line of drill rigs engaged in exploratory boring. (Photograph taken November 26, 1907. Board of Water Supply)

heal up the fractures and so make the rock about as substantial as before.

It is noted elsewhere that faulting is common in this region, and that in a considerable portion of its lower course the Hudson probably follows such structures. It is, however, wholly unnecessary to assume that its whole course is a fault line. Whether or not there is a longitudinal fault zone of any prominence in the river at Storm King is unknown. There are several cross faults, both above and below this point, that give much clearer surface evidence of their presence. Fault zones have proven to be objectionable ground in many places along the aqueduct line, but elsewhere the data refer chiefly to situations favoring more ready underground circulation, i. e. at higher levels. In this particular case the rock in question lies below former ground water level within the belt of cementation rather than up in the belt of decay, and there is probably no disintegrated rock from any cause.

CHAPTER IV

GEOLOGICAL FEATURES INVOLVED IN SELECTION OF SITE FOR THE ASHOKAN DAM

Topographic features of the southeastern margin of the Catskills, where the chief water supply is available, fixes the approximate location and bounds of the principal reservoir. The accompanying map, a portion of the western part of Rosendale quadrangle, shows the situation. The part of the work involving the chief geological problem was the choice of the principal dam sites on the Esopus. This is known as the Ashokan dam. This part of the Catskill system belongs to the Reservoir Department under Mr Carlton E. Davis as department engineer.

There were originally considered three sites: (1) at "Broadhead bridge," (2) at "Olive Bridge," (3) at "Cathedral gorge" or the "Tongore" site. Any one of these seemed possible from a topographic standpoint. Later developments in regard to storage capacity and engineering considerations finally reduced the practicable sites to two—the "Olive Bridge" and the "Tongore." These were then explored thoroughly as an aid to determining whether or not there were favorable or unfavorable conditions at either location. Trenches were dug, shafts were sunk, wash holes were put down, and drill borings were made. The amount of such work done was sufficient to show the actual conditions both of the drift and bed rock and incidentally to throw some light on minor matters in geologic history.

This discussion is essentially a summary of these data and a comparison of the geologic conditions indicated by the explorations¹ of these two sites and a statement of some of the geologic characteristics of the area.

1 General geologic conditions as shown by the explorations

Bed rock is dark colored Devonian sandstone and shale, the Sherburne formation, lying almost horizontal, strongly jointed, plainly bedded, and of good quality for the foundation of the dam.

At both locations the present Esopus flows in a postglacial gorge

¹ In this work of exploration a very efficient staff of engineers was engaged. Among those having very much to do with the features here discussed are Thaddeus Merriman, division engineer, J. S. Langthorn, division engineer and Sidney Clapp, assistant engineer.

and there is a somewhat deeper buried channel a short distance to the north side. In each case this old channel bed rock is probably less fresh and substantial, due to former weathering, than the present exposed surfaces.

In each case glacial deposits reach a thickness of more than 200 feet within the narrow valley or gorge, especially along the north valley wall within the limits of the proposed dam.

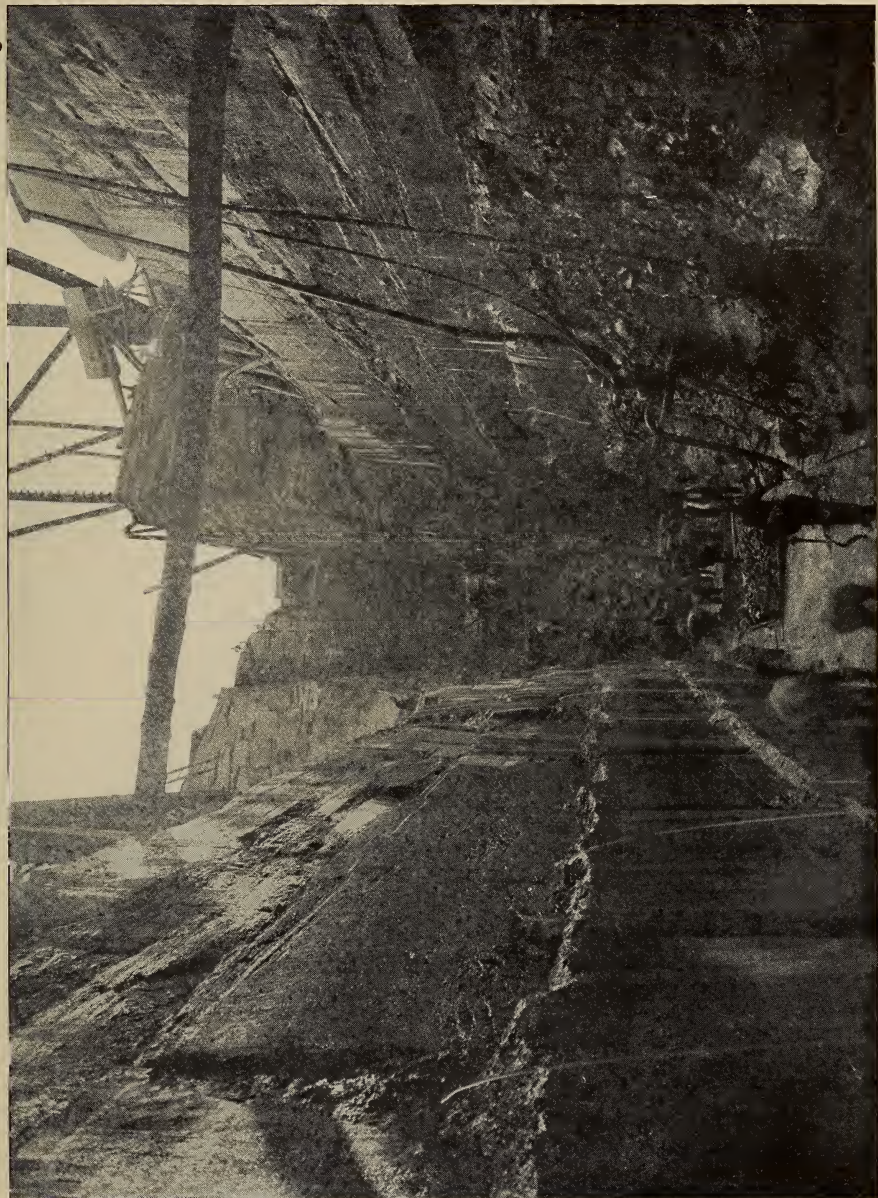
Special geological conditions. The factors in which there is most variation and which are of most significance in a comparative study are those belonging to the glacial drift deposits. In order to properly estimate the influence of some of these features it will be necessary to briefly consider the types of material represented at different places and the conditions under which they were formed.

Types of material. *Till.* Heavy bouldery till, mixed clay, sand, gravel, and boulders, is the most abundant type of material. It forms especially the chief surface material throughout the region, and is the surface type at both sites. It becomes at places quite sandy, but is almost everywhere good, impervious material because of its mixed character.

Laminated till. At a few places, notably in the Beaver kill near its mouth, and in a trench above Olive Bridge, and in the "big dugway" above West Shokan, strong lamination appears in heavy stony till as if laid down rapidly in comparatively quiet water such as the margin of a lake. This material is especially impervious.

Gravel hillocks. A few small hillocks with morainic contour, indicating a dumping ground for some glacier on a small scale, occupy the flat immediately west of Browns Station. They were, at a very late stage, piled into the course of a former glacial stream whose delta deposits occupy the sandy bench above the 500 foot contour just north of Olive Bridge.

Assorted gravel and sand. This material is abundantly developed just north of Olive Bridge. It seems to have formed a delta deposit at the mouth of a glacial stream that emptied into the main valley at this point. The running water washed almost all of the clay and extremely fine material farther out, where they settled in the bottom of a small glacial lake that was at that time held in this upper portion of the Esopus valley. The dam that held in this body of water which reached above the 520 foot line stood near the proposed "Olive Bridge" dam site. The materials forming the dam were in part the glacial till that is now found on that site and



Cut-off trench in the Sherburne sandstones and shales at Olive Bridge dam (Ashokan). (Photograph by Board of Water Supply)



in part the ice itself, which came in from the northeast, helping to complete the barrier. Into this lake the streams from the melting ice margins deposited their load of silt. This is well shown in the trenches cut across the terrace $\frac{3}{4}$ of a mile above Olive Bridge.

A similar occurrence is seen at the cemetery near West Shokan.

Laminated sand and clay. In all cases where silts were carried into the lake basin the finest materials were carried in suspension to greater distances from the margins, and slowly settled out in the form of alternate laminae of clay and fine sand. Each sandy layer represents a fresh supply of material and rapid precipitation of the comparatively heavy grains; while each clay layer represents a period of greater quiet or decreased supply during which the finest particles settled to the bottom. A predominance of fine sand indicates either abnormal supply or proximity to the supply margin, while a predominance of clay represents either uniform and moderate supply or greater distance from the supply margin.

These deposits are nearly impervious to water moving vertically, but much more pervious laterally and especially so in the most sandy portions forming the marginal facies.

This type of deposit is to be seen at the surface at about the 700 foot contour 2 miles north of Shokan, above the "big dugway," also in the trenches cut into the terrace at about the 500 foot contours $\frac{3}{4}$ of a mile north of Olive Bridge, and it is probable that this same type underlies the northern half of the "Tongore" site. The material marked "fine sand" at and below the 400 foot line on the accompanying "geologic section" *G-H* is judged to be of this type.

Pebbly clays. These are developed to only limited extent and indicate probably floating ice in addition to the other methods of distribution.

Gravel streaks and assorted pebble beds. Wherever water flowed with considerable current across the material either before or after deposition the finer particles were removed and only gravel and pebbles, too heavy to transport, were left behind. Some of these gravel beds were developed in the intervals of successive advances and retreat of the ice when for a time the lower valleys were unoccupied. In many places the succeeding advance of the ice would plow all these surface materials up again and mix them into the usual till; but occasionally the oncoming glacier simply covered these deposits with its own till mantle, and they are preserved as records of these minor interglacial stages. Such behavior would be

more likely to occur in the deeper channels. To this class of deposit belong some of the gravel beds of the "Tongore" site, notably that shown in one of the deep shafts. It is probable that the zones where the wash rig experienced a "loss of water" are most of them of this type.

2 Summary of geologic history

In preglacial time the Esopus valley was occupied by a stream of similar capacity to the present Esopus creek. Its channel lay to the north side of the narrow valley, having adjusted itself in conformity to the slight dips of the Hamilton sandstones and its principal joints. At the points under investigation this original channel is buried under several kinds of glacial deposits whose source of accumulation was chiefly from the north and northeast, blocking the stream channel and forcing the stream to the opposite (south) side. The direction of movement was favorable to the damming of the Esopus creek valley and the deposits indicate that this occurred at several different times and at different elevations and that corresponding lake conditions occasionally prevailed. It is equally clear that there were intervals of retreat of the ice with attendant stream action and the development of gravel beds, followed by another ice advance, either obliterating the surface features or covering the previous deposits with another till layer. With each successive withdrawal the local streams found themselves more or less completely out of place, and consequently their characteristic deposits formed in these intervals may be found in unlooked for places wholly inconsistent with present surface contour.

At the final withdrawal of the ice, Esopus creek found itself entrenched along the southern margin of the valley and has cut a postglacial rock gorge instead of removing the compact till from the original channel. But wherever only modified drift, either sand or clay, was the valley filling it scooped out great bends so that a large proportion of this type has been removed from the valley, and only the margins remain as terraces or covered beneath other protecting deposits.

3 Application to the choice of dam site

a "Olive Bridge" site. The trenches and shafts together with surface exposures indicate that the glacial drift at the Olive

Plate 19



View across the Esopus valley to "Millwheel Gap." In a portion of this glacial lake basin modified sands and clays were deposited while an ice barrier closed the outlet of the valley. The "Gap," the sharp notch in the lower slope of the mountain, is interpreted by Darton as the outlet or overflow for the surplus waters during that stage. (Photograph by Mr J. E. Hyde of Columbia University)

Bridge site, at one stage in the glacial history, served as a natural dam and that water was successfully held above it to an elevation of 530 feet and perhaps more.

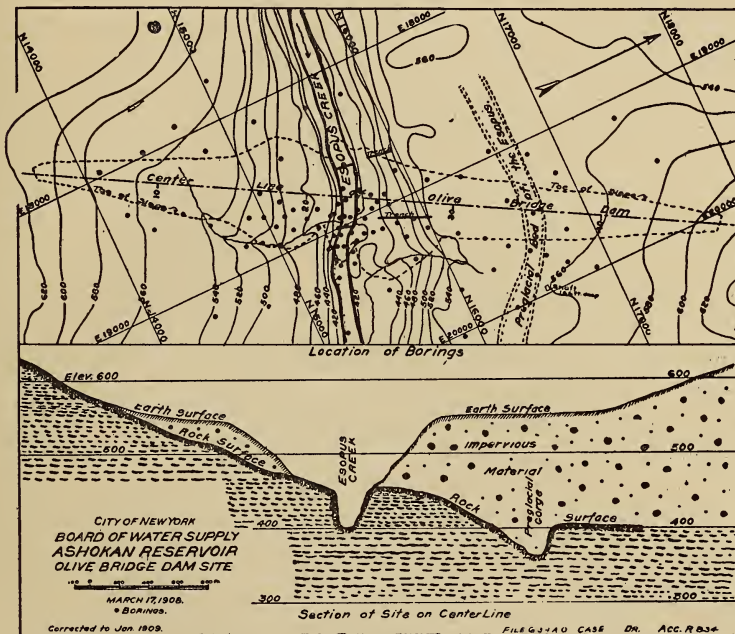


Fig 16 Location of the Ashokan dam at Olive Bridge site and a geologic cross section. The small dots in the plan indicate exploratory borings. The section shows the rock profile indicating a preglacial channel of the Esopus. The present Esopus flows in a new postglacial channel at a higher elevation.

The lowest materials in contact with bed rock are heavy stony till, laminated till and stony laminated clays — all good impervious material wherever exposed and tight upon bed rock. Sands and laminated clays are extensively developed immediately northward of the site and streaks of these deposits interlock to a limited extent with the till materials of the site itself, but they do not extend far and die out in wedges among the heavy deposits that characterize the southern slopes of the hill forming the northern terminus of the dam. These pervious streaks do not extend at any point continuously through this hill and consequently as a whole the present barrier as it stands is practically impervious. The poorer materials (assorted gravels and sands) characterize the upstream side, and the better, more impervious materials (till and laminated boulder clays) characterize the downstream side of the proposed Olive

Bridge site. It is therefore advisable to locate any such structure as a dam at a point as far down stream on this site as other engineering factors permit.

b "Tongore" site. At Tongore, bed rock is at least a hundred feet deeper than at Olive Bridge. In the deeper parts, below the 400 foot line the deposits as indicated by the wash borings [see sections] are interpreted as a fairly continuous succession of till, stratified sands and gravels, and laminated sands and clays belonging to two or three different stages of accumulation. Upon this the heavy upper till was laid down. It is believed that the records fully support this view and that the stratified or laminated materials were accumulated at a time when a temporary dam existed at some point still farther down the Esopus valley. It is apparent furthermore that the most porous zone is at the junction of the upper till and the lower stratified deposits and in part is represented by the assorted pebbles of stream wash—in general not far from the 400 foot line. These middle zone deposits are believed to extend continuously through the drift ridge that forms the northern half of this site. As before noted, though rather impervious vertically,

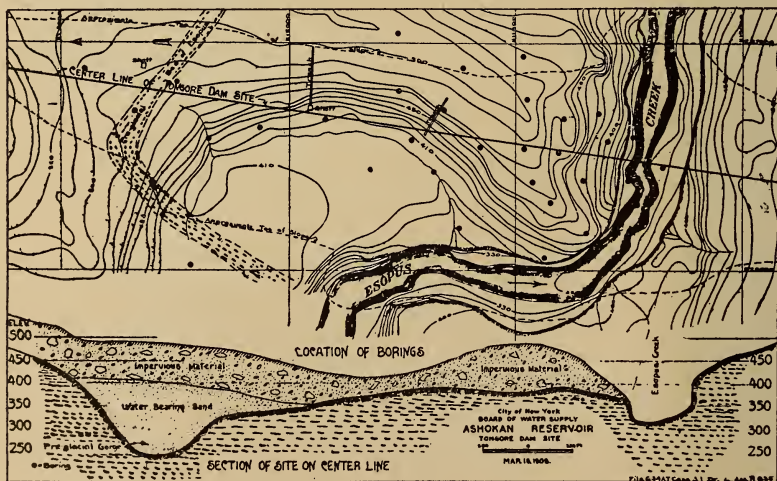
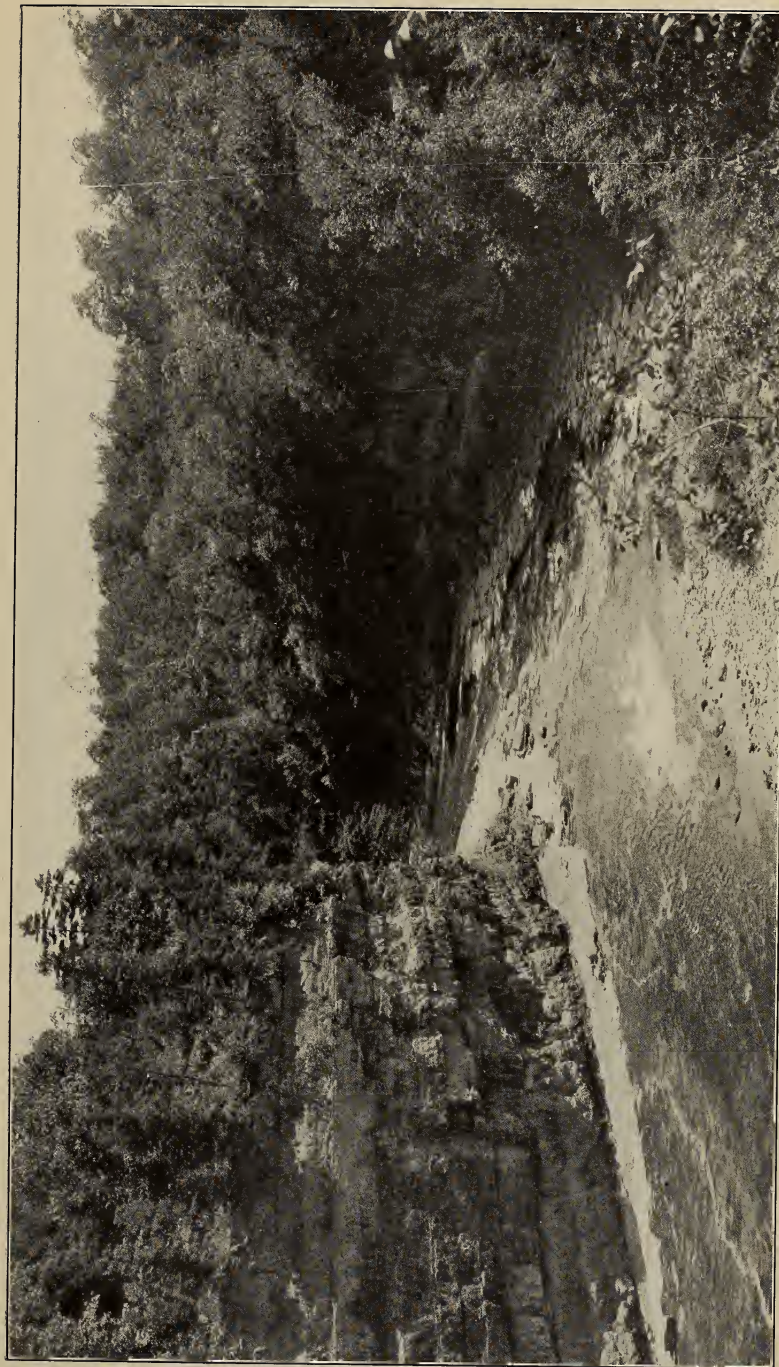


Fig. 17 Plan and geologic section at the Tongore site. The dots on the map indicate exploratory borings and the course of the buried channel of the preglacial Esopus creek is shown making a right angle bend to the north. The section shows the buried channel, the new postglacial channel and the great accumulation of porous modified drift which is regarded as one important objection to this site for the dam.

some of these deposits allow ready lateral movement of water. This is held to account for the rather persistent occurrence of springs or seepage along the creek bank at about this level both above and

Plate 20



Cathedral gorge, a postglacial entrenchment of Esopus creek at the Tongore site. The preglacial gorge lies at the north side of the valley buried beneath 250 feet of drift. (Photograph by Board of Water Supply)

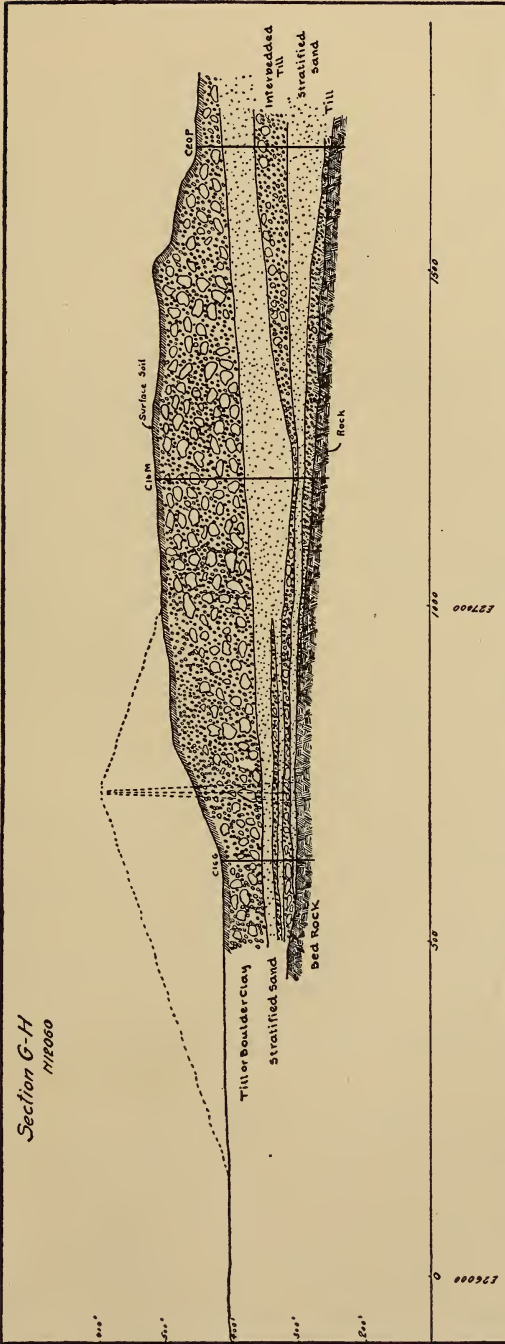


Fig. 18 Detail of drift character at the Tongore site showing extensive and continuous stratified sands characterizing this location, which, because of their perviousness, represent poorer geologic conditions than were found at the rival Olive Bridge site.

below the site. The great thickness of these laminated beds, in places a hundred feet or more, together with the abundance of sand in them, and the caving tendencies exhibited by them in one of the large shafts, indicates poor conditions for such a piece of work.

The behavior of one of the test shafts throws some light on conditions within the drift deposits. At this place after sinking into the underlying gravel beds there was "no water" at first, but after going a few feet deeper there was an abundant flow, that did not rise much in the shaft. This case seems to support the following interpretation.

The gravels encountered do not form an isolated pocket or lens, else it would have carried water full from the first. It must be a fairly continuous porous zone with large feeding connections else it would run dry, and it must have an easy discharge else it would have risen above the level of the first gravels. Therefore it must be a rather well marked subterranean water passage or porous zone of considerable extent. Such conditions would make an impervious core wall to bed rock at this site a necessity and its construction a matter of considerable difficulty. At this site also because of the small cross section of the ridge, there is little chance for the interlocking of layers or the blocking of the porous ones by a till barrier to check the lateral seepage, and there is no chance to move farther down stream to secure such conditions.

4 Summary

Because of the (a) higher bed rock throughout, and (b) the more uniform and impervious quality of drift deposits, and (c) the more massive cross section of drift barrier for foundation, and (d) the perfectly tight contacts of till and bed rock, and (e) the limitation of the more porous materials to higher levels and (f) the glacial history connected with the development of all these parts, "*Olive Bridge*" is the preferable location for the proposed Ashokan dam on Esopus creek.

CHAPTER V

CHARACTER AND QUALITY OF THE BLUESTONE FOR STRUCTURAL PURPOSES

Probably no stone marketed in New York State is more extensively known than the "bluestone" of the Catskill region. But it is noted particularly for a special purpose, i. e. as flagstone, because of its capacity to part or cleave into thin slabs. These slabs are proven by experience to have remarkable weather resistance and durability.

Little attention has been given to the question of dimension stone — whether or not such blocks of as high quality as the flags could be obtained and where such quarries could be opened.

There are several reasons for this situation. In the first place (1) the stone is of a dark color and has a dull appearance so that it is not fancied for the usual expensive structures where large sizes are used, also (2) the quarries are small, shallow, and are worked on a small scale by single individuals or groups of neighbors with few quarrying tools and no transportation facilities for large material, and in addition (3) considering the work and equipment necessary and the demand the flag industry was more profitable.

Because of the large demands of the Ashokan dam where nearly a million cubic yards of heavy masonry construction are to be used an entirely new situation has developed. It is especially desirable that a rock capable of furnishing heavy dimension blocks should be discovered. The usual slab or flag type is unsuited to a considerable part of this work. A study of the adjacent region therefore has been made and explorations along certain promising lines have been conducted to sufficient completeness to prove that a suitable stone can be furnished in large quantity. The characteristics of structure and occurrence as shown by this special study are given, together with some of the later exploratory data.

Physiographic features¹

All of the rock formations are sedimentary, chiefly sandstones and shales. They lie in alternating beds of variable thickness and are almost horizontal. The total thickness is many hundred feet so

¹ The principal argument of this discussion has been used in a previous article by the writer under the title "Quality of Bluestone in the vicinity of the Ashokan Dam" in the *School of Mines Quarterly*, v. 29, no. 2.

that neither the bottom nor the top beds of the series are to be seen in this locality.

The region is one of considerable relief representing preglacial erosion. The glacial drift mantle has modified it chiefly by obscuring some of the smaller irregularities of rock contour, and especially by partially filling many of the stream gorges. Postglacial erosion has not completely reexcavated the old channels. But the contour of the uplands reflects the character of the bed rock with considerable success. The tendency of the more massive and coarse grained varieties of rock to resist weathering and erosion more successfully than the finer grained and more argillaceous or shaly facies is a general characteristic. Since these varieties form successive or alternating beds throughout the whole area, the result is an almost universal cliff-and-slope surface form. This bed rock topography is somewhat obscured but not wholly obliterated by glacial erosion and deposition. Therefore it may be used with confidence in locating or tracing the more durable beds since they almost invariably appear as a shelf or terrace with a steep margin toward the lower side and a gentle slope on the rising side.

Structural features

The rock types include bluish gray or greenish gray sandstones with almost horizontal bedding, and sometimes exhibiting cross-bedding structure, and compact very dark argillaceous shales. These two are of about equal prominence, but only the sandstone is of importance in the present discussion. Its minute structure will be given in greater detail in the petrographic discussion.

Jointing is common and persists in two sets nearly at right angles to each other — one striking northeastward and the other toward the northwest. In some of the best exposures, these joints are clear-cut and run 10 to 18 feet apart, dipping almost vertically. In the more massive beds there is very little small jointing, so that the character is especially favorable to large dimension work.

But still more prominent structures are the partings which follow the bedding planes. These give the rock a decided tendency to cleave naturally into slabs, the uppermost exposed portion of almost every outcrop exhibiting this slab structure in more or less perfection. So general is this structure at all horizons in the sandstones of the series that there can be no doubt of its connection with some original sedimentation character. Besides it is a potential factor in nearly all the beds even when not very apparent. The



The Sherburne flags, showing their horizontal bedding and two very regular and prominent sets of joints.
(Photograph by Board of Water Supply)

exposed places exhibit the character so prominently only because of the weathering effect, which develops the natural tendency. This general conclusion is borne out by the well known practice of quarrymen of the district of splitting the larger blocks into slabs of the required thickness by wedges driven along certain streaks that are known as "reeds." A reeding quarry is one that has this capacity well developed, and it is this character in part that has made the "bluestone" or "flagstone" of New York an important factor in the production of the United States for a great many years.

For large size dimension stone where great stress is involved it is evident that this structure would not be desirable. These definite planes of weakness reduce the general efficiency. A little observation however shows that there are some outcrops and an occasional quarry where the more massive blocks do not split well. From the necessities of the industry these have been avoided or but meagerly developed. In some cases of this kind the sedimentation is of the cross-bedded type with somewhat interlocked laminae. If the grain is coarse such varieties resist splitting with great success. The thickness of such beds varies from a few feet to 25 feet or even more without prominent interbedding of shale layers.

Stratigraphy. These are the sandstones, flags and shales known as the Hamilton, Sherburne and Oneonta formations belonging to the Devonian period. The strata of the immediate vicinity of this examination belong to the Sherburne subdivision, but no attempt to differentiate the formations was made. Structurally and petrographically the different formations are not distinguishable in this area. On the market the stone from either is known generally as "Hamilton flag" or "bluestone."

Economic features

There are hundreds of quarries in this general region. Nearly all are small, and are worked on a small scale without machinery. The product is almost wholly thin slabs of the flagstone type. This is supplemented by a small amount of somewhat more massive character, dressed for window sills; and a very limited output is of dimension stone of larger size. The general lack of suitable mechanical devices and transportation facilities are the chief reasons for the limited output of the last named grades.

Petrography

The basis of this discussion is a microscopic examination of several thin sections made of the different types of rock from the

quarries whose field geologic features give promise of encouraging results. The most characteristic variations are illustrated in the accompanying photomicrographs, plates 22, 23.

Texture. The rock is granular, the individual grains varying from minute particles in the finer shale layers to three or four tenths of a millimeter in diameter in the coarser sandstone [pl. 23, lower figure]. The grains are seldom rounded. Jagged or frayed or elongate forms are the rule [pl. 23, upper figure]. There is no marked porosity. When the rock was first deposited as a sediment it probably had the usual large interstitial spaces of such rock type, but in this case some subsequent modification — an incipient metamorphism — has largely obliterated the voids by the introduction or development of mineral matter of secondary origin.

In general it is quite apparent that the average grain was originally more rounded than its present representative.

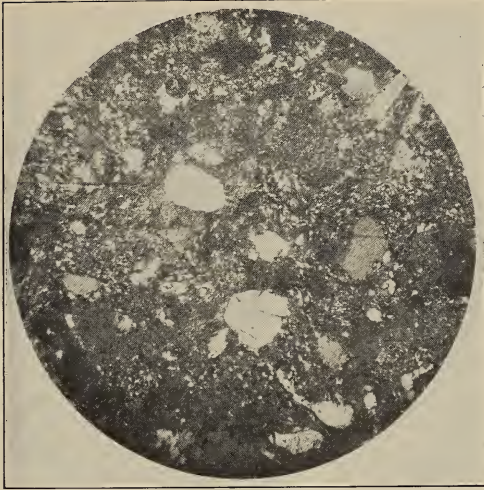
Mineralogy. The original minerals in order of abundance were the feldspars, quartz, and probably hornblende, biotite, and in much smaller amounts others of little apparent consequence in the present discussion.

All of these have been more or less affected by subsequent changes. Quartz has suffered least of all, the chief modification being a greater angularity of form and an occasional interlocking tendency caused by secondary growth [pl. 22, lower figure].

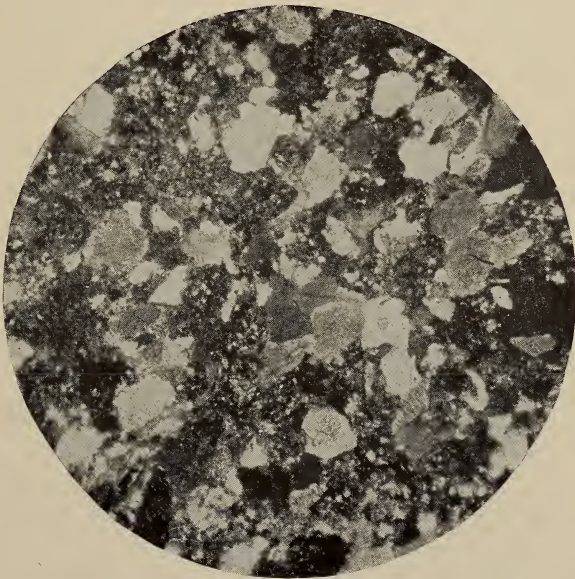
Both orthoclase and plagioclase feldspars occur. The orthoclase grains, which originally made up more than half of the bulk of the coarser types of rock, have been in places profoundly altered [pl. 22, upper figure]. In many cases the identification of this mineral depends upon its association and the abundant remnants of characteristic structure and its normal secondary products. In the least affected grains satisfactory identification is not difficult. Even in the most modified representatives there is some preservation of structure indicating size of grain and proving the essentially granular character of the rock. The plagioclase, although not abundant, is more readily detected than the orthoclase because it has been much less affected by the secondary changes.

All original ferromagnesian constituents are wholly altered. There were some such constituents in the rock, as is plainly shown by the secondary products. Hornblende and biotite were probably both present.

The secondary products, derived from the original feldspars and ferromagnesian constituents, include sericite, chlorite, calcite and



Photomicrograph of bluestone, x 25 diameters. The clearer grains are quartz and indicate the approximate size of other original constituents. In this case the alteration of the feldspars and ferromagnesian originals is so complete that their products form an indeterminable complex aggregate of closely interlocked granules, flakes, and fibers of extremely fine texture.



Photomicrograph of first grade medium grain bluestone, x 25 diameters. Taken to show angular and interlocking grains indicating secondary growth and a complete lack of reeding structure. The clear grains are quartz; the rest of the field is made up chiefly of secondary derivatives from the original feldspars and ferromagnesian minerals.

quartz as the most important and abundant. Others probably occur that are less readily differentiated, and among them is kaolin. Occasionally a small amount of massive or granular pyrite occurs. There are traces of organic remains, especially plant stems, and the pyrite is most plentiful in association with those beds.

It seems to be the secondary products largely that give the characteristic bluish or greenish color to this stone. Practically all of the iron freed by secondary changes from the ferromagnesian constituents has entered into new silicate compounds, especially with the chlorite, which are minutely distributed throughout the whole mass, giving it all a tinge of the characteristic color of these well known products. The same amount of iron in the oxid form would no doubt give as highly colored stone as any of the reds or browns of other familiar types of sandstone. But the tendency to form the sericite-chlorite-quartz aggregate in the rock has also an important bearing on its durability and strength. This is further discussed in a separate paragraph.

Classification. It is clear that this type of bluestone is a sedimentary rock of medium grain, a sand rock or "renyte." Since the silicates are so predominant in the original composition it may be further identified as a sandstone or a "silicarenyte." But in view of the predominance of the feldspars it should be further designated as an arkose sandstone. And considering the extent to which it has been modified by the development of interstitial silicious products and the effect that this has had in perfecting the bond between the grains, the rock may be classified as an indurated arkose sandstone.

Special structure. A study of the cause of reeding, or the tendency to split into slabs, led to the preparation of thin sections of this structure [pl. 23, upper figure]. It is apparent from them that the reed is strictly a rock structure and that the perfection of the capacity to split along these planes depends wholly upon the abundance and arrangement and size of the elongate and semifibrous grains and the presence of a more than usual amount of original fine or flaky material. Almost universally the reed streaks are darker in color and finer in grain than the average of the rest of the rock.

In part therefore it is an original character due to the assorting action of water during deposition, finer streaks alternating with coarser ones in accord with ordinary sedimentation processes. But, in addition to that, the subsequent changes that have affected the whole rock have occasionally accentuated the structure by a ten-

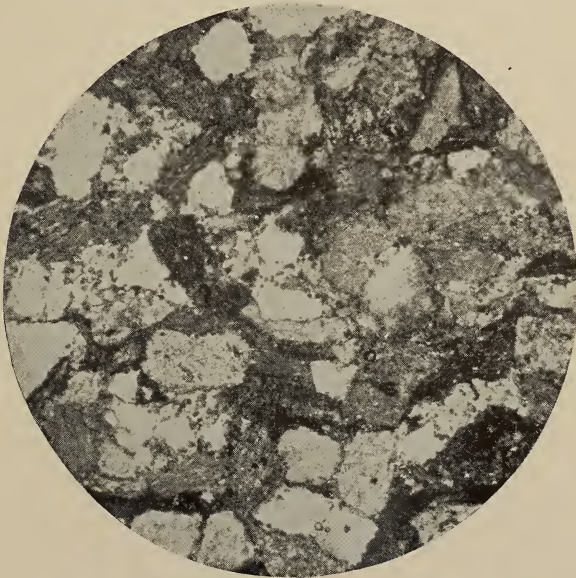
dency of the whole rock to develop elongate or fibrous aggregates. It is probable therefore that the parting capacity is in places considerably increased by the very process that has produced just the reverse results in the more heterogeneous portions of the beds.

Under a sufficient stress the rock will part most easily along the planes where this foliate or fibrous character is most persistent. Even in these cases, however, it may not indicate that the rock is essentially weak. It simply locates the most vulnerable point in the stone. In many quarries these streaks are so abundant that only thin slabs can be obtained—the disturbances of ordinary quarrying being sufficient to cause parting. The deeper portions of quarries are, however, much less subject to such behavior. In all cases the greater slab development of the exposed portion of the ledge is an ordinary weathering effect, by which the same results are obtained slowly and naturally and more perfectly than can be secured artificially on the fresh material of the same beds. The expansions and contractions of changes of temperature, together with the rupturing effects of freezing water caught in the pores, serve finally to weaken every part of the rock. In this process the prominent reed lines give way so much in advance of the rest of the rock that they develop into true rifts and separate slabs appear. It must be appreciated that these ledges have been exposed an immensely long time compared with the probable requirements of any engineering structure, and that this weathering tendency does not mean a speedy disintegration of the freshly quarried blocks. Still it is advisable to avoid as many sources of weakness as possible and one of the ways is to select ledges where the stone does not have a reeding tendency, or in which the reed lines are interlocked, or wavy, or interrupted. These requirements are most fully met in the coarser beds and especially those exhibiting some cross-bedding. Two local quarries meet these demands to a marked degree.

Strength. The better qualities of bluestone have great strength. Even the reed lines are in many instances stronger and more durable than the regular quality of some other sandstones that are usually considered suitable building material. The secret of this exceptional strength lies in the modifications of texture that have resulted from the alteration and reconstruction of the mineral constituents. The breaking up of the orthoclase feldspar, and the accompanying changes in the ferromagnesian minerals, have furnished considerable secondary quartz, which has in part attached to the original quartz grains making them more angular and de-



Photomicrograph showing structure of the reeding quality of "blue-stone." Magnification 30 diameters. Taken to show tendency to parallelism of elongate grains.



Photomicrograph of best grade coarse-grained bluestone. Taken to show a quality in which the granular character is still well preserved. The clear grains are quartz, the others are chiefly feldspars somewhat modified. The close interlocking and the development of fibrous or frayed structure and the bending or wrapping of some constituents are secondary effects.

veloping an interlocking tendency [pl. 22, lower figure]. At the same time the fibrous sericitic and chloritic aggregates have developed to such extent as to fill most of the remaining pores, and in many cases the fibrous extensions have actually grown partly around the adjacent quartz grains [pl. 23, lower figure]. The effect has been to develop a silicious binding of unusual toughness. This combination of changes has made a rock that is now remarkably well bound or interlocked for a sedimentary type.

Durability. First-class stone of the grades indicated above would have as great durability as any stone in the market, except perhaps a true quartzite. With the exception of the almost neglectable quantities of pyrite, occasionally found, there is no constituent prominently susceptible to decay. The rock as a whole mineralogically is stable and its texture indicates unusual resistance to ordinary disintegrating agencies.

General conclusions

From the microscopic study it is clear that the variety of rock most fully meeting the demands of heavy exposed construction are the coarser beds and those freest from reef and shale.

From the field study it is apparent that ledges of suitable character occur occasionally and that at least three such are not far from the Olive Bridge site.

From additional explorations it is certain that ledges of high grade rock occur, and that the grade varies rapidly in the same bed and that suitable material can be obtained in the immediate vicinity of the Ashokan dam. No doubt rock of equally high quality may be obtained at many other localities.

CHAPTER VI

THE RONDOUT VALLEY SECTION

Because of the fact that the hydraulic grade of the Catskill aqueduct as it approaches the Rondout valley is nearly 500 feet A. T., an elevation more than 300 feet above the lowest portions of the valley and more than 200 feet above very large areas of it, a total width of more than 4 miles being too low for unsupported construction of some kind, and because of the general policy of using the pressure tunnel system so as to deliver the water at a corresponding elevation on the east side of the valley, and further because of the very complicated geological features of the district this section has been the seat of very extensive and interesting explorations.

Undoubtedly a greater number of obscure features occur here than on any other single section of the whole aqueduct line. Most of these features are readable from surface phenomena in general terms. In all cases the indications are plain enough to serve as a guide to well directed tests, but many points of critical importance can not be determined with sufficient detail and accuracy of position for such an engineering enterprise without systematic exploration.¹ The basis and results of this line of investigation which has occupied the greater part of two years are summarized and plotted in the following discussion and charts. The portion receiving special study is in the vicinity of High Falls.

General geology

Almost everywhere the surface is glacial drift. Where outcrops of bed rock occur they habitually present the unsymmetrical ridge appearance usually with a more or less sharply marked escarpment on one side and a gentle slope on the other. The strike of these

¹ These explorations belong to the Esopus division of the Northern Aqueduct Department. The earliest reconnaissance was done under the direction of James F. Sanborn, division engineer, who was subsequently assigned to geologic work over a considerable portion of the Aqueduct line. The development of exhaustive explorations and final construction on this division has been carried on under Lazarus White, division engineer, assisted by Thomas H. Hogan. The division has been recognized from the beginning as an important one and in many ways one of the most complex. Thomas C. Brown, now professor of geology in Middlebury College, was employed for a year on this division during the later exploratory work.

features is in general northeasterly and on the gentle slope is the westerly one.

It is apparent at once that the valley bottom is a complex one and that its history has been somewhat obscured by the glacial deposits.

Formations. The following distinct stratigraphic units are determinable in this valley every one of which will be cut by the tunnel beginning at the west side with the youngest formations :

	Feet
Hamilton and Marcellus flags and shales.....	700+
Onondaga limestone	200
Esopus gritty shales.....	800+
Port Ewen shaley limestone including the Oriskany transition.....	250+
Becraft crystalline limestone.....	75
New Scotland shaley limestone.....	100
Coeymans limestone	75
Manlius limestone including Rosendale, Cobleskill, and the cement beds	100+
Binnewater sandstone	50
High Falls shale including small limestone layers.....	75
Shawangunk conglomerate	250 to 350
Hudson River slates — thickness unknown; probably more than.....	2000

Approximately 4775

These occur in belts in succession more or less regularly from west to east. Most of the formations are quite uniform in the Rondout valley. The Shawangunk conglomerate is probably more variable than any other as shown by borings. Because of this general persistence of formation it is possible to estimate approximately the depth at which any particular lower member lies if some starting point can be identified. [For detailed description of the formation, *see* pt 1]

Structure. The principal irregularities are structural, rather than stratigraphic. The region on the west side of the valley, the margin of the Catskills, is but slightly disturbed and lies very flat, but the region on the east side, the Shawangunk mountain range and the cement district, has an extremely complicated structure. The Rondout valley, lying between them, is a transitional zone and passes from gentle dip slopes and folds in the westerly side to more frequent folds and thrust faults on the easterly side. In at least two thirds of the valley it would appear from surface evidence alone that the formations would dip uniformly westward, the only suspicion of additional complication being given by an occa-



A minor fold in the Binnewater sandstone and High Falls shale at High Falls on Rondout creek. (Photograph by Columbia University Summer School in Geology. 1907)

sional minor fold seen in the river gorge or an escarpment where the sedimentary character alone would hardly account for it [*see* pl. 24, High Falls]. Explorations have shown that the evidence of the minor structures is reliable and that disturbances occur at some places even to the extreme western margin.

Physiography. In spite of the drift cover which obscures many original inequalities it is readily seen that the prevalence of the gentle westerly dip over most of the area, together with the succession of so many different beds of varying resistance to erosion, have allowed the development of a succession of long dip slopes and steep escarpments on a more pronounced scale than the present topography shows. It is clear that the Rondout is really a series of these unsymmetrical valleys. The principal large dip slopes are formed by the Shawangunk conglomerate and the Onondaga limestone. In each case an original stream had adjusted its course fully to the structure and was shifting slowly by the sapping process to the west against the opposing edges of the overlying strata which form the bordering escarpment. One of these unsymmetrical valleys lies along the easterly base of the Hamilton escarpment and is continuous with the lower course of Esopus creek farther to the north. In the area under special study it is not occupied by a stream now but is filled with glacial drift so completely that the original stream has been evicted. It is evident, however, from computations based upon the average dip of the slope carried to the base of the escarpment that the bed rock floor ought to be from 200 to 300 feet below the present surface in the deepest portion. Borings have proven this to be the case both along the present line near Kripplebush and also on the first trial line across the Esopus at Hurley.

The same thing is true near High Falls in the center of the valley where Shawangunk conglomerate forms the dip slope and the escarpment is formed by the Helderberg limestones. In this case the drift filling is very deep also, and Rondout creek flows upon it quite independent of rock structure except where it has cut across the margin as at High Falls.

In the eastern half of the valley the hard Shawangunk conglomerate forms the chief rock floor and largely controls the contour by its own foldings and other displacements. Thus the Coxing kill tributary valley lies in a syncline of the conglomerate with occasional remnants of overlying beds as outliers adding some variety to the form. The Shawangunk mountains, as a physiographic

feature, owe their present elevation chiefly to the resistance of this conglomerate which serves as a protective member among the formations.

On the west side, the foothills of the Catskills form a part of the cuesta developed by the erosion of Paleozoic sediments, the inface coinciding with the escarpment along the lower Esopus and Rondout valleys at this point.

It is certain therefore that the drainage of the Rondout valley before the Ice age differed materially from the present lines. A stream, probably the original Rondout, followed near the western margin of the valley and joined the Esopus as it emerged from the Hamilton escarpment to turn northeast. Another which had cut somewhat deeper occupied the central portion of the valley and probably joined the Esopus at some point farther north — its lower course is not explored.

Practical questions

The chief practical questions to be given as full answers as possible are:

1 At what depth must the aqueduct tunnel be placed in order to be everywhere in substantial bed rock with sufficient cover to be safe?

2 Where are the most critical places — those whose geologic characters are such as to demand exploration? And at the same time which sections may be safely left without testing?

3 What is the rock structure and condition? And are there reasons for believing that the tunnel plan is not feasible at this point. If so, where can a better one be found?

4 What is the character of underground circulation of water?

5 What formations will be cut at the different points and which should be favored or avoided wherever possible?

From the fact that the present Rondout flows across solid ledges at High Falls and at Rosendale from 100 to 200 feet above the known rock floor of the preglacial gorge where explored it is clear that the present course is entirely different from the original. The Coxing kill, the third and most easterly of these streams is not so much disturbed although it also is shifted.

It is worth noting that the streams of this valley together with the lower Esopus and the Wallkill river have become so completely adjusted to the rock structure that they all flow up the larger Hudson valley, of which all form a part, and join the master stream

at an obtuse instead of the usual acute angle. They are essentially retrograde streams.

Explorations. Systematic explorations and tests are represented chiefly by drill borings through drift into the rock floor. These were supplemented by two test tunnels for working character of material and a series of tests on the behavior of certain of the drill holes, together with other tests on material. The results are embodied in the accompanying cross sections and the additional discussion of special features.

Detail of local sections

Kripplebush section. This from the first was regarded as one of the critical sections because of the buried gorge along the base of the Hamilton escarpment and because of the doubt as to the behavior of the Onondaga limestone. On the accompanying section the borings are plotted and the structure as now interpreted is indicated. The dip slope formed by the Onondaga limestone is covered by 200 to 250 feet of drift, mostly modified drift. The strong valley character of the rock floor is almost wholly obscured by the glacial deposits and the present brook, an insignificant stream compared to the preglacial one, occupies a position above the escarpment instead of above the old channel.

After a couple of the central holes were finished, it became apparent that the structure is not nearly so simple at this point as the general surface features would lead one to expect. It was clear that a simple dip such as was proven to prevail on the dip slope would not account for the much greater depth attained by it in the vicinity of station 500. The discovery of this additional feature raised two questions: (1) Is the structure a flexure or is it a fault, and if a fault whether normal or thrust, and (2) what is the probable effect of this structure on the position and depth of the preglacial gorge?

The habit of the district immediately east of the valley would support the theory of a thrust fault. The nature of the immediate area would suggest a simple flexure while it is manifestly possible that a normal fault could easily occur. Later explorations¹ have

¹ Since the above was written the tunnel has been completed through the Kripplebush section. Although faulting is indicated by the borings and actual occurrence of the beds it is very difficult to find the fault. A part of the displacement is accomplished by the steepening of the dip but this will not account for more than half of it.

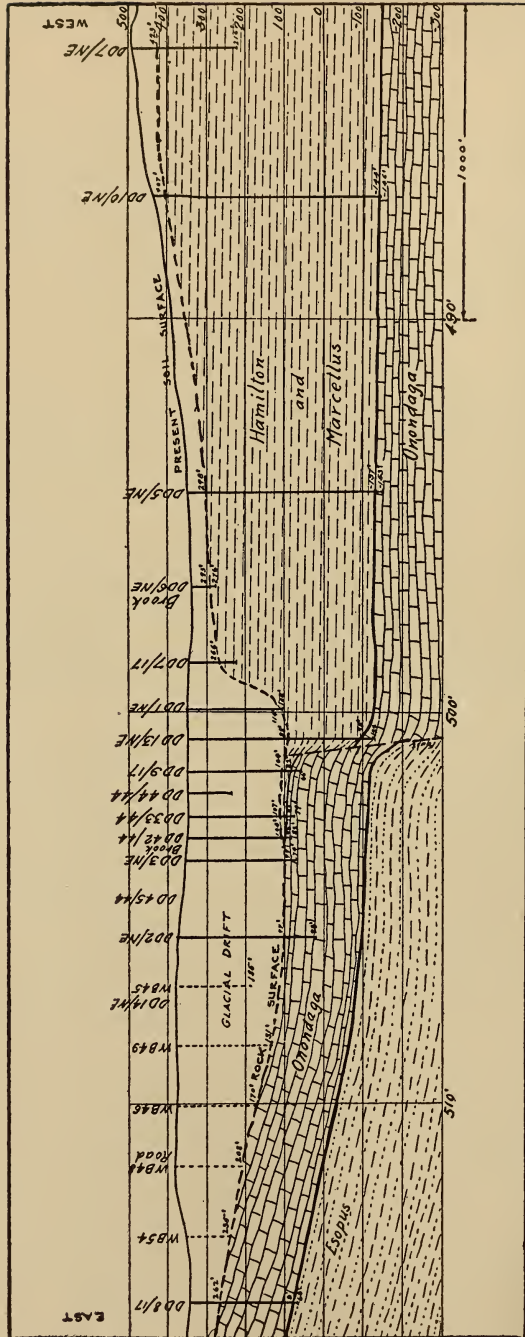


Fig. 19 Geologic cross section of the Rondout tunnel line as interpreted from drill borings

tested this zone so well that it is practically certain that the feature must be regarded as a fault of some type with a displacement of nearly 200 feet. The striking physiographic feature is the development and preservation of the escarpment on the downthrow side. This occurrence is certainly a very unusual case in that regard [*see fig. 19*].

Because of the intention to construct the tunnel deep enough in bed rock to reach safe rock conditions the question of depth of buried gorge becomes an important one. As soon as it was discovered that a fault existed there the problem became of sufficient prominence to demand more detailed exploration. If the faulting is accompanied by a broken zone in condition favorable to more ready erosion, it would be possible that the original stream in working down this dip slope might become entrenched in the fault zone and at that point begin to cut a narrow gorge instead of continuing the sapping process. In fact, it would undoubtedly do this very thing if there is such a crushed zone of any consequence and if the erosion process were allowed to continue long after reaching this critical point.

As a matter of fact explorations have shown that there is a thin layer of Hamilton shales still remaining on the Onondaga and the deepest point found is on the Hamilton shales side. These facts in connection with the failure to find any deep notch indicate that there is probably no zone of much greater weakness than the shale member itself. It is reasonable to conclude that the rock floor can be safely regarded as not much lower than 88 feet A. T. and that the rock condition is not especially bad for tunnel construction¹ even in the fault zone.

Rondout creek section. This is the central portion of the valley including the depression occupied by the present Rondout and the exposed edges of the series of shales and Helderberg limestone. The repetition of the dip slope and escarpment, together with the heavy drift filling and the occurrence of so many formations together make this an important section. All formations from the Shawangunk conglomerate to the Port Ewen shaly limestone occur at this point, and although there is little outward evidence of disturbance it is certain that whatever difficulty is to be found in this variable series is likely to be met here. It is therefore a section that requires exploration both for depth of preglacial channel and for quality of rock.

¹ In construction this ground has proven to be good and sound throughout.

All of the formations dip westward wherever exposed, but the dips vary somewhat, nearly all being of low angle. Occasional minor inequalities of the nature of small rolls may be seen, as, for example, the small fold in the gorge at High Falls [*see* pl. 24].

Explorations have shown, as indicated on the accompanying cross section [fig. 20], that there is a deeper buried gorge here than at Kripplebush. The deepest point discovered is a few feet below tide level. The escarpment is steep and is formed by the Coeymans and New Scotland formations. The dip slope is Shawangunk conglomerate, High Falls shale and Binnewater sandstone, with the Manlius limestone forming the floor.

Identification of the drill cores which penetrate the limestone indicate that the dip slope is reversed on the west side of the gorge and that the stream had really reached about the axis of the trough. A discrepancy in thicknesses and depths in hole no. 34 by which it appeared that the Coeymans formation was almost twice as thick as usual and that it contained a broken or crushed zone leads to the interpretation that there is a small thrust fault here which repeats the formation as shown on the accompanying cross section.

Instead of a uniform westerly dip of all formations from the Rondout westward it is proven that minor anticlinal rolls and even thrust faults, as in this case, or such faults as in the Kripplebush case are not to be excluded.

This structural relation has a direct bearing upon the question of the thickness of the Esopus shales. The Esopus is certainly not so thick as would otherwise be supposed, by 200 or 300 feet at the least. The true thickness is still an unknown quantity (estimated at 800 feet).

It is clear that the aqueduct tunnel will have to be constructed a considerable depth below sea level at this section, probably not less than minus 150 feet,¹ even if the character of the formations be neglected.

But the character or quality of these formations in view of their structural relation constitutes the chief problem. Because of the fact that every structure reaches the surface and eventually dips gently to the west in such manner as to encourage water circulation, their water-carrying capacity or general porosity becomes of great importance. A great capacity is all the more serious because of the heavy drift cover within the abandoned gorge, on top of which

¹ This portion of the tunnel and its continuation south to the Shawangunk range has been constructed at 250 feet below sea level.

the stream flows and which constitutes essentially an unlimited storage reservoir to feed underground circulation. This is all the more true if crush zones are extensively developed as accompaniments of the faulting.

In general as to perviousness the indications are somewhat obscure. But the data now obtained seem to prove that all the formations except the Binnewater sandstone and the High Falls shale are compact and fairly impervious along the bedding lines. Only where crevices have formed or where crushing occurs is there likely to be heavy circulation. This is all the more important since so many of the beds are limestones known to be readily soluble in circulating water. One of these limestones, the Manlius, exhibits occasional large open solution joints at the surface — so large that a surface stream disappears entirely at the so called "Pompey's cave" and joins the subterranean circulation. But such caves are probably limited to the surface.

It is near this point, however, that one of the earlier borings at one side of the present line discovered very soft ground at a depth of about sea level, i. e. over 200 feet below the present surface, which shows that similar conditions prevail at certain points to great depth.

Pumping tests made on hole no. 32 in an attempt to establish some data on the inflow of water gave very interesting results. These tests were very thorough. It was proven that the water was supplied in apparently inexhaustible quantity at maximum pumping capacity, which was ninety gallons per minute. Furthermore, the chief inflow seemed to be from the Binnewater and High Falls formations as was to be expected. Whether a crush zone allowing free circulation is furnishing a portion of this supply or whether the whole inflow represents the normal porosity condition of these formations is not yet proven.¹

Other porosity tests have been made in such way as to locate and measure this factor [*see* later discussion]. Hole no. 10 shows an artesian overflow that comes from the Binnewater sandstone. A working shaft has been put down also in the vicinity of hole no. 32 and at the same depth found an enormous inflow of water which drowned out operations for a time. The lateral supply in this case has been reduced by introducing a thin cement grouting through holes bored in the surrounding rock from the surface.

Holes no. 12 and no. 14 also show an artesian flow, but both are

¹ In construction the Binnewater sandstone has been found very wet.

shallow holes and the supply comes from near the contact between High Falls shale and Shawangunk conglomerate.

It is certain from these observations and tests therefore that the Binnewater sandstone and High Falls shale are more porous than the other formations, and because of the serious difficulties arising from so heavy inflow of water from them the tunnel grade should be shifted so as to avoid these formations as much as possible. A comparison of the accompanying cross section, which is drawn to scale [fig. 20], will show that a tunnel on one level would necessarily run for a long distance in these beds because of the gentle syncline. Furthermore, they lie at about the depth that would otherwise be a safe depth below the buried gorge. But a tunnel with a step-down, i. e. one run at two different levels could avoid most of this poor ground. By approaching at a level of about — 50 feet or — 100 feet in the limestone beds to station 600 (hole no. 34), then stepping down to — 250 feet, the line in a very short distance crosses these two porous formations and enters the Shawangunk conglomerate which is more substantial, and, all things considered, one that seems most advantageous for successful construction. It will have to maintain a head of more than 700 feet as the difference between hydraulic grade and the tunnel level in this section. Under these conditions rock quality and condition are of greatest importance and there is no doubt about the advisability of avoiding the poorest formations in some such manner.

Coxing kill section. On the line of exploration the Coxing kill flows over Shawangunk conglomerate and High Falls shale. Both dip plainly eastward, and a hole no. 11 located on the east side of the brook penetrates about 70 feet of drift and shale. But only a hundred feet to the east Shawangunk conglomerate outcrops at the surface dipping the same way. It is certain therefore that a fault occurs here. The dip of the fault plane is indeterminate from the surface, but the relations and surroundings indicate a fault of the thrust type.

Later explorations indicate that the fault plane is rather flat [see cross section fig. 21] so that the shales are repeated above and below a tongue of conglomerate. Boring no. 11 has also an artesian flow of considerable volume coming from near the bottom of the conglomerate. It is a mineral water.

The chief importance of this section as a problem in applied geology lies in the influence of the fault and the maximum depression of the conglomerate. If the tunnel, which enters Hudson River slates at the Rondout creek section at — 250 feet can be kept within that formation throughout the rest of its course,

there is no doubt that an advantage will be gained both in the greater imperviousness of the rock and the greater ease of penetration. Wherever the conglomerate is undisturbed it is perfectly good, but where broken the crevices are but imperfectly healed and circulation is unhindered. It would therefore be desirable to know whether at — 250 feet the whole of the downward wedge of Shawangunk could be avoided. The borings indicate a thickness of Shawangunk of 345 feet in hole no. 11 where it is cut at a small angle, and a thickness of 409 feet in hole no. 36 where it probably lies pretty flat. This greater thickness together with the

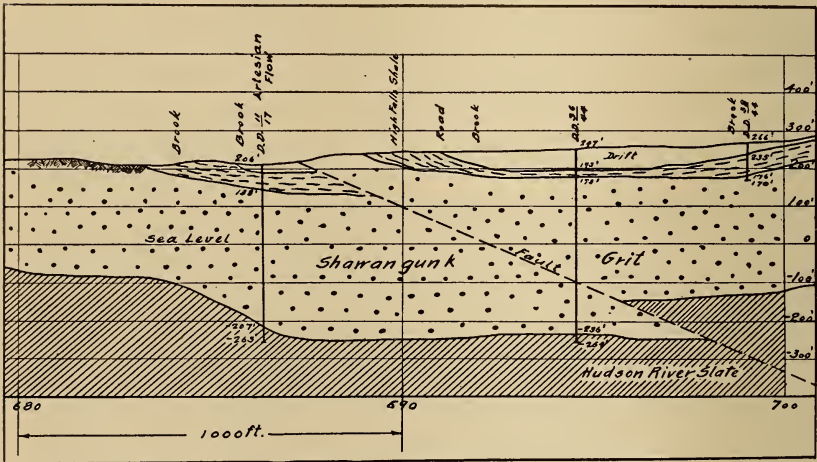


Fig. 21 Structural geologic detail of the Coxing kill section

finding of crushed rock at about the — 100 foot level leads to the conclusion that the formation is overthickened here by the thrust fault to the extent probably of about 75 feet. The true thickness of the formation at this point is doubtless more nearly 300 feet than either of the figures obtained directly from the two holes. If this interpretation is used as the basis of plotting a cross section [see accompanying cross section] it is apparent that the conglomerate should not be expected to extend more than a few hundred feet east of hole no. 36 and it probably does not reach a much greater depth than the — 236 feet represented as its base in that boring.¹

¹ Construction of the tunnel has progressed far enough through this section to prove that the Shawangunk formation does not reach much lower. It forms the roof of the tunnel for some considerable distance but does not come down into the tunnel more than a foot or two.

Shawangunk overthrust. At the extreme eastern side of the Rondout valley near the point where the surface reaches hydraulic grade again, the surface outcrops pass from High Falls shale to Shawangunk conglomerate to Hudson River shale in the normal order but with entirely too small an area of conglomerate considering the character of the formations. The higher ground is all Hudson River in the vicinity, and there is abundant evidence of crushing and disturbance. It is evident that a thrust fault is again encountered here, one of sufficient throw to bring the Hudson River slates above the Shawangunk conglomerate—probably a lateral displacement of very great extent. Explorations have fully proven the existence of this fault. The accompanying diagram shows a cross section as now outlined by complete penetration of two borings.

Two trial tunnels were run to test working quality of Hudson River slates compared to Shawangunk conglomerate at this locality. Both are within the influence of the fault zone. Both are therefore more broken than the normal with the result that the Hudson River slates probably show poorer condition than usual and more troublesome working, while Shawangunk conglomerate probably shows easier working than usual. It is believed that normally the two rocks would present a greater difference than was found in this test.

Special features

Several questions, some of which have a practical bearing, have been raised as separate features during the exploration of the Rondout valley.

Caves. One of these is in regard to the possible existence of underground caverns. This was given a special prominence early in the work by the experience of one of the drills. After penetrating the limestone series near High Falls to a depth of over 200 feet, the drill seemed to leave the rock and enter a space allowing the rods to drop 28 feet before being arrested by solid material. The further attempt to work in this hole resulted in the breaking of the rod down at this point and the subsequent failure to recover the diamond bit which is still in the bottom of the hole. The question is as to the meaning of this occurrence. Is it a cavern?

“Pompey’s cave” has been referred to in an earlier paragraph. This is clearly not much of a cave. It is essentially an enlarged joint or series of joints by solution along the bed of a surface

stream to such extent that the stream normally at present has become subterranean. It is the writer's opinion that the case encountered by the drill boring is similar. The apparent cavern is probably a slightly enlarged joint along a line of somewhat abundant underground circulation and perhaps associated with some crush zone developed by the small faulting known to occur in this immediate vicinity. It is probably not entirely empty but contains residuary clay, and in all likelihood is very narrow and not exactly vertical, so that the drill rods were bent out of their normal course and wedged into the lower part of the crevice. Smaller spaces of this sort were encountered at a few other points.¹

These occurrences seem to indicate that the limestone beds yield rather readily to solution by underground water, and that this circulation has been at one time active to at least 50 feet below present sea level. With present ground water level nearly 200 feet above sea level it is extremely unlikely that any such action is going on at so great depth. The occurrence is therefore strongly corroborative of former greater continental elevation when the deep stream gorges, now buried, were being made. These deeper caverns or solution joints probably date from that epoch.

Imperviousness and insolubility. The question of imperviousness and closely associated with it that of solubility, is of great practical importance in this particular work. The immense pressure under which the tunnel will be placed in crossing this valley makes it impossible to construct a water-tight lining. Everywhere much depends upon the rock walls to help hold the water from serious loss. Wherever the rock is fairly impervious except occasional crevices or joints they can be grouted and safeguarded satisfactorily. But where a formation is of general porosity this can not be so successfully done. Even more difficult to handle is the rock wall which is soluble and which therefore with enforced seepage may tend to become progressively more porous. That this consideration is not wholly theoretical is shown very forcibly by the Thirlmere aqueduct of the Manchester (England) Waterworks. In that case a 3 mile section was built through limestone country using the same local limestone for concrete aggregate. Although

¹In constructing the tunnel several clay-filled spaces have been discovered in the same vicinity at elevation—100. One of these extended vertically with a width of 1 to 2 feet and from it a great mass of mud ran into the tunnel. At one point it was connected with a horizontal space of the same kind extending 15 feet. It can be seen that the original crevices have been enlarged by water and that they were originally formed during faulting.

this concrete was mixed as rich as 1 part cement to 5 parts aggregate and the work was well done, excessive leakage reaching a total of 1,250,000 imperial gallons per day was developed within a year. It was found that the limestone fragments of the aggregate were corroded forming holes through the lining of the aqueduct and that these holes actually enlarged outward. All this was done under cut and cover conditions with not more than a 6 or 7 foot head on the bottom of the aqueduct.

In the Rondout valley, the aqueduct will cut no less than 6 limestone beds in all cases under great pressure. This fact will in all probability tend to increase the action. But, of course, some of the beds may not yield so readily to solution. Tests made thus far, however, indicate that all are attacked in water. Considering these facts it seems desirable, so far as possible, to avoid the limestone beds wherever rock of greater resistance to solution can be reached, and further it is equally desirable to use a more resistant rock for the lining concrete. So long, however, as the formation is not very pervious so that a new circulation could not be established by the escaping water there would be little harmful effect.

An average of five analyses of the Thirlmere limestone, different varieties of the same formation, gives the following:

Insoluble silicious matter.....	2.772%
Alumina and iron oxid $Al_2O_3+Fe_2O_3$	0.276
Lime, CaO	53.676
Magnesia, MgO .....	.390
Carbonic anhydrid, CO_2	42.248
Total	99.362

Estimated calcium carbonate, $CaCO_3$ — 95.85%

The limestone is fossiliferous.

Suitable analysis of the limestones of the Rondout valley are not recorded in sufficient numbers. But these are a few, as given below.

BECCRAFT LIMESTONE.	At Rondout	At Wilbur	At Hudson (av'ge of 2)
SiO_2	3.87%	7.10%	1.865%
Al_2O_3	1.07	2.50	.818
Fe_2O_3	1.34	1.65	1.185
CaO	54.11	45.32	51.375
MgO	tr	tr	2.870
CO_2	40.60	39.10	40.795
Total	100.99	95.67	98.908
Corresponding to total calcium carbonate..	96.62	80.75	91.74

This is a limestone that in composition and structure at the Rondout valley is apparently not very different in quality from the Thirlmere rock. Analyses of the cement rock show less similarity but observations indicate that it is also attacked.

It is probable from all these facts that the shales and conglomerates are better quality of wall than the limestones.

A very acute observation along this line by Dr Thomas C. Brown while employed on the staff of the Board of Water Supply is of special interest. In studying local conditions he noticed that the limestone blocks used in building the old Delaware and Hudson (D. & H.) canal showed the effect of contact with the water. The best place for measurable data seemed to be around the old locks where squared and evenly trimmed blocks had been used. These were, during the years of its use, from 1825 (approximately 35 to 40 years) subject to the action of water flowing or standing in direct contact. The coigns of the locks, which were without doubt freshly and well cut when laid, are now etched till the fossils and other cherty constituents stand out from one eighth to one half inch beyond the general block surface, and in some cases the pits are an inch deep. That this etching is due to the water rather than to exposure to weather is shown by the lack of such extensive action on blocks used in houses and exposed a much longer time. Blocks representing the Manlius and Coeymans were identified. But there is no reasonable doubt that others would be similarly affected. On some it would be less easily detected.

On account of the disturbances another factor is introduced. Rocks which readily heal their fractures are likely to furnish better ground, i. e. more free from water circulation especially, than rocks which are brittle and slow to heal. Therefore in this district the shales and slates such as the Hudson River series and the Esopus and Hamilton shales are the best ground, while the Binnewater sandstone is the poorest.

Cross sections. Probably in no region of like extent is it possible to construct a geologic cross section of so many complex features so accurately as can now be done of the Rondout valley along the aqueduct line. The section is known or can be computed to a total depth below the surface of 1000 feet, including 12 distinct formations, so closely that any bed or contact can be located within a few feet at any point throughout a total distance of over 4 miles.

The accompanying cross section contains as much of this data as is now available [fig. 22].

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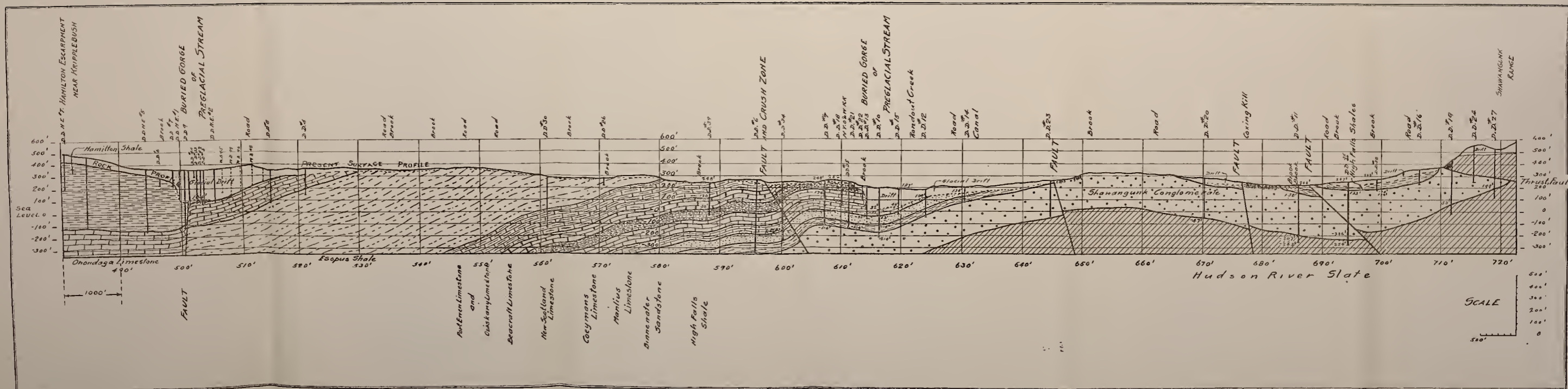


Fig. 22 Geologic cross section of the Rondout valley
 Constructed from the data secured in exploratory borings on the Rondout pressure tunnel line

Rondout siphon statistics

1 **Total borings on the siphon line.** Three different boring equipments have been used owned by different parties and records have been kept so that the work of each can be followed or compared with the others.

On this division the Board of Water Supply owned and operated one machine with their own men, another equipment was owned and operated by C. H. McCarthy, while a third which finally did a majority of the work, belonged to Sprague & Henwood, Contractors, of Scranton, Pa.

The totals of different general types of material penetrated by these machines are as follows:

	Feet of drift	Feet of rock	Total feet of depth	Per cent of core saved
<i>a</i> B. W. S. Equipment.....	1740.5	2175.5	3916	89.4
<i>b</i> Sprague & Henwood.....	3647	6831	10478	60.04
<i>c</i> McCarthy machine	181	1228	1409	78.1

The average saving of core by all machines, cutting all kinds of bed rock was 75.96%

2 **Core recovery from various strata.** So nearly as can be done the strata represented in the drill cores have been identified and summarized as to total penetration and core saving. The core saving is a factor of prime importance in judging of the quality of rock and its freedom from disturbance. The following items are gathered from a study of the whole series.

a Holes 6, 10, 12, 13, 15, 17, 18, 21, 22 and 25 penetrate Helderberg limestone, a total combined depth of 1096 feet. Individual holes vary in core saving from 39.3% (no. 13) to 95.3% (no. 15). The average core saving is 78.19%.

b Holes 8 and 9 are in Onondaga limestone with a total penetration of 197 feet. The core saving varies from 56.2% to 92% with an average of 74.5%.

c Holes 11, 19, 20, 23, 24, 27 penetrate Hudson River shale and together represent a total of 696.5 feet. The core saving varies from 16.6% to 89%, with an average of 42.1%.

d Holes 6, 10, 11, 12, 14, 16 and 20 cut High Falls shales to a combined total of 410 feet. The saving varies in different holes from 17% to 83.3%, with an average core saving of 44.5%.

e Holes 8 and 26 penetrate Esopus shale and penetrate 76 feet.

The core saving varies from 73% to 84.6%, making an average of 78.8%.

f Holes 10, 11, 12, 14, 16, 19, 20, 23, 24 and 27 penetrate Shawangunk conglomerate a total of 1356.5 feet. Core saving varies in different holes from 33.3% to 100%. The average recovery is 60.52%.

g Holes 6, 10, 12, 15 and 16 cut Binnewater sandstone. The total penetration is 205 feet. The range of core saving is from 30.6% to 74.7%, with an average of 56%.

h Holes 7 and 9 cut Hamilton shales to a total amount of 65 feet. The range of saving is 70% to 81.8%, with an average of 75.9%.

3 Artesian flows. Several of the borings struck artesian flow of water. The fact that the sources of this flow are not the same has led to a tabulation of these data.

RECORD OF ARTESIAN FLOWS

Hole no.	Size in inches	Static head in feet	Flow gallons		Flow encountered at elevation Feet	Strata
			Minute	Day		
10	1	18	30	43 200	-109	Binnewater sandstone
11	1	10	10	14 400	- 60	Shawangunk conglomerate
12	$\frac{3}{8}$	1	.....	.....	- 24	High Falls shales
14	$1\frac{3}{4}$	.....	.....	.....	+ 90	"
20	$\frac{3}{8}$	7.5	10	14 400	+108	Shawangunk conglomerate
23	2	.....	.....	.....	- 5	"
31	2	.....	.....	.....	+158	"
39	$1\frac{1}{2}$	.....	.....	.....	+112	Helderberg limestone
5NE	$\frac{3}{8}$	12.4	.....	432	+203	Hamilton shale (possibly drift)

Pumping experiments and porosity tests

Systematic tests have been made for flow of water, behavior of ground water and porosity of rock on certain of the Rondout exploratory holes under the direction of Mr L. White, division engineer. A summary of these tests has been furnished by him from which is quoted the following:

In addition to determining the location and thickness of the beds and the general character and condition of the rock from inspection of the cores, serious attempts were made to determine the relative porosity and water-bearing quality of the rocks encountered for the following reasons. (1) To determine the probable leakage from the siphon when in operation. (2) To determine the probable amount of water to be handled in construction. These experiments were divided into three classes: (1) Observation of flow from cer-

tain drill holes which showed sustained flow of water. (2) Pressure tests in which water was pumped into holes which had been sealed off and pressure and leakage noted. (3) Pumping tests in which water was pumped from 4 inch drill holes by means of deep well pump of the type used in oil wells, and fall of ground water during pumping and subsequent rise after cessation of pumping noted. A description of the first two and the results obtained from them follows:

A substantial flow of water was observed from the following holes:

11/17: 50 gallons per minute through 2½ inch pipe, static head 10 feet

10/17: 30 gallons per minute through 1½ inch pipe, static head 18 feet

20/17: 10 gallons per minute through ¾ inch pipe, static head 7.5 feet

The static head was observed by adding on lengths of pipe until the water ceased to flow over. It will be noticed in the case of hole no. 10 that the flow from the 1½ inch pipe is not that due to static head of 18 feet, but that due to a head of only ½ foot. In other words the friction head is about 17.5 feet, and the velocity head only ½ foot. This same condition holds true of the other holes from which a flow was obtained. This would seem to indicate that the amount of water is not very great but that it is under considerable pressure. It is believed that this pressure is caused by gas.

A slight flow was observed from the following holes: 12/17, 14/17, 23/17, 31/44, 39/22, and 5/NE.

The flow from most of these holes has ceased since the pipe used in boring was withdrawn. There is still some flow from the following holes: 11/17, 20/17, 25/17 and 5/NE.

The flow from hole 11/17 is constant at about 10 gallons per minute. The others are too small to be measured. It will be noted that the only substantial flows encountered were from the High Falls shale, Binnewater sandstone and Shawangunk grit, and that it was possible to force water into these rocks in greater quantities and at a less pressure than in the other shales and limestones.

Porosity tests. The method of making these tests was as follows:

Wash pipe equipped with a device for sealing the hole was lowered to the desired elevation. The seal consisted of alternate layers of rubber and wood around the pipe preventing the water from escaping between the walls of the hole and the pipe. Water was then pumped in and pressure and leakage noted.

The result of the pressure tests was to show in a general way: (1) That the pressure increased with the depth of seal. (2) That the leakage decreased with the depth of seal. (3) The maximum pressure in the grit was 140 pounds to the square inch and minimum

leakage was 5 gallons per minute. (4) In the Hamilton shales a pressure of 300 pounds to the square inch with very little leakage was obtained.

The unknown factors are too many and too great to make any reliable deductions from these experiments.

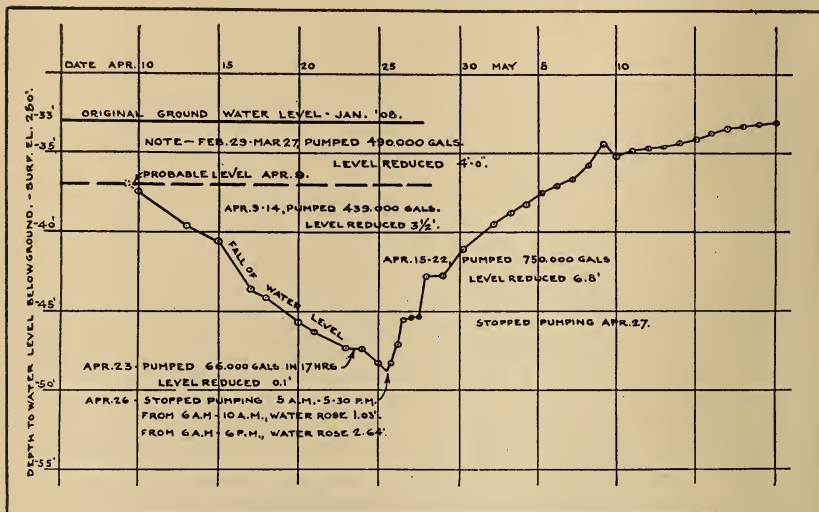


Fig. 23 Curve showing fall of ground water level while pumping from boring 34

Pumping experiments were carried on in holes 32/22 as follows: The apparatus used was a deep well pump of the type used in oil wells. The holes were of an inside diameter of $4\frac{1}{4}$ inches and were cased to the bottom. A $3\frac{1}{2}$ inch working barrel was then lowered to the bottom of a line of wooden sucker rods. The stroke was 44 inches and the nominal capacity of pump at 38 strokes per minute was 60 gallons per minute or 86,400 gallons per day. The power was obtained from a 40 horsepower boiler and 35 horsepower engine belted to a 10 foot band wheel which was connected to a 26 foot walking beam. In hole 32/22 at station 607 + 50 the average discharge at 38 strokes per minute was 90 gallons per minute or 129,600 per day. The experiment was continued for 15 days and the total amount of water pumped was 1,071,000 gallons. The ground water level was not lowered. It will be noticed that the discharge at this point was 50% in excess of the theoretical capacity of the pump. This was caused by the presence of gas, the effect of which seemed to be increased by the churning action of the pump. This may also explain the failure to lower the ground water.

The experiment at hole 34/22 was similar in character. The upper 230 feet of this hole had an interior diameter of $4\frac{1}{4}$ inches

and the bottom 274 feet a diameter of only $3\frac{1}{4}$ inches. At first a $2\frac{1}{4}$ inch working barrel was used to pump from the bottom and a discharge at 32 strokes per minute averaged 24 gallons per minute or 34,500 gallons per day. This was continued for about 15 days and the total quantity pumped was 490,000 gallons. The ground water level was lowered 17 feet at hole 34 and 4 feet at hole 32, 750 feet away.

The $3\frac{1}{4}$ inch pump was then let down to a depth of 200 feet with a $2\frac{1}{2}$ inch casing reaching down to the Binnewater sandstone, depth of 437 feet. The average discharge at about 40 strokes per minute was 60–65 gallons per minute, or an average of 90,000 gallons per day. It will be noted that the discharge was much smaller than at hole 32 owing to the absence of gas. Pumping with a $3\frac{1}{4}$ inch pump was continued 16 days and 1,532,000 gallons of

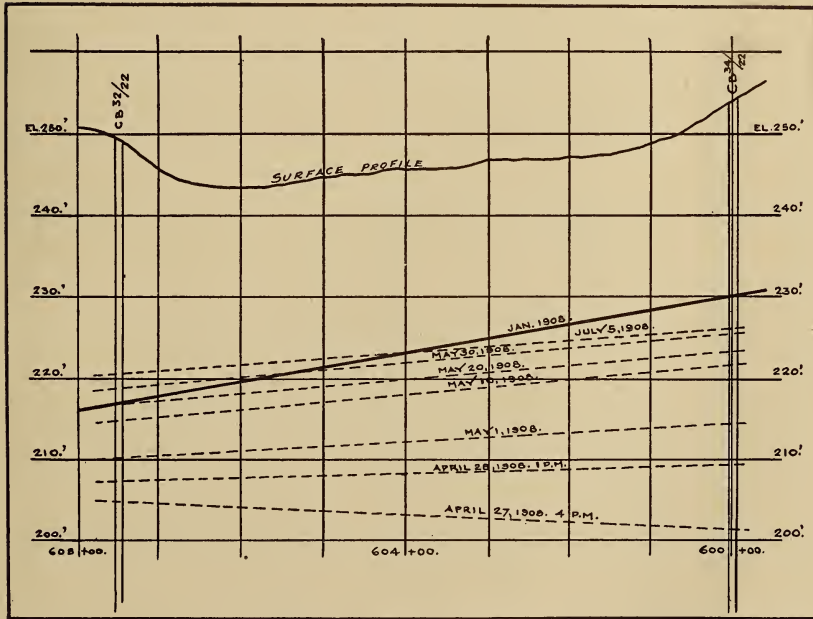


Fig. 24 Diagram showing successive stages of ground water level between holes 32 and 34 during pumping

water were pumped in addition to the 490,000 gallons from the $2\frac{1}{4}$ inch pump. The ground water level in hole 34 was lowered 36 feet in addition to the 17 feet by the $2\frac{1}{4}$ inch pump, but rose 9 feet in 20 minutes, and 30.5 feet in the next five days. In the next 22 days it rose 9.15 feet, or .42 feet per day.

Reduced water level in hole 32, 750 feet away by pumping in 34, 15 feet, or 1 foot for each 120,000 gallons pumped. In the first

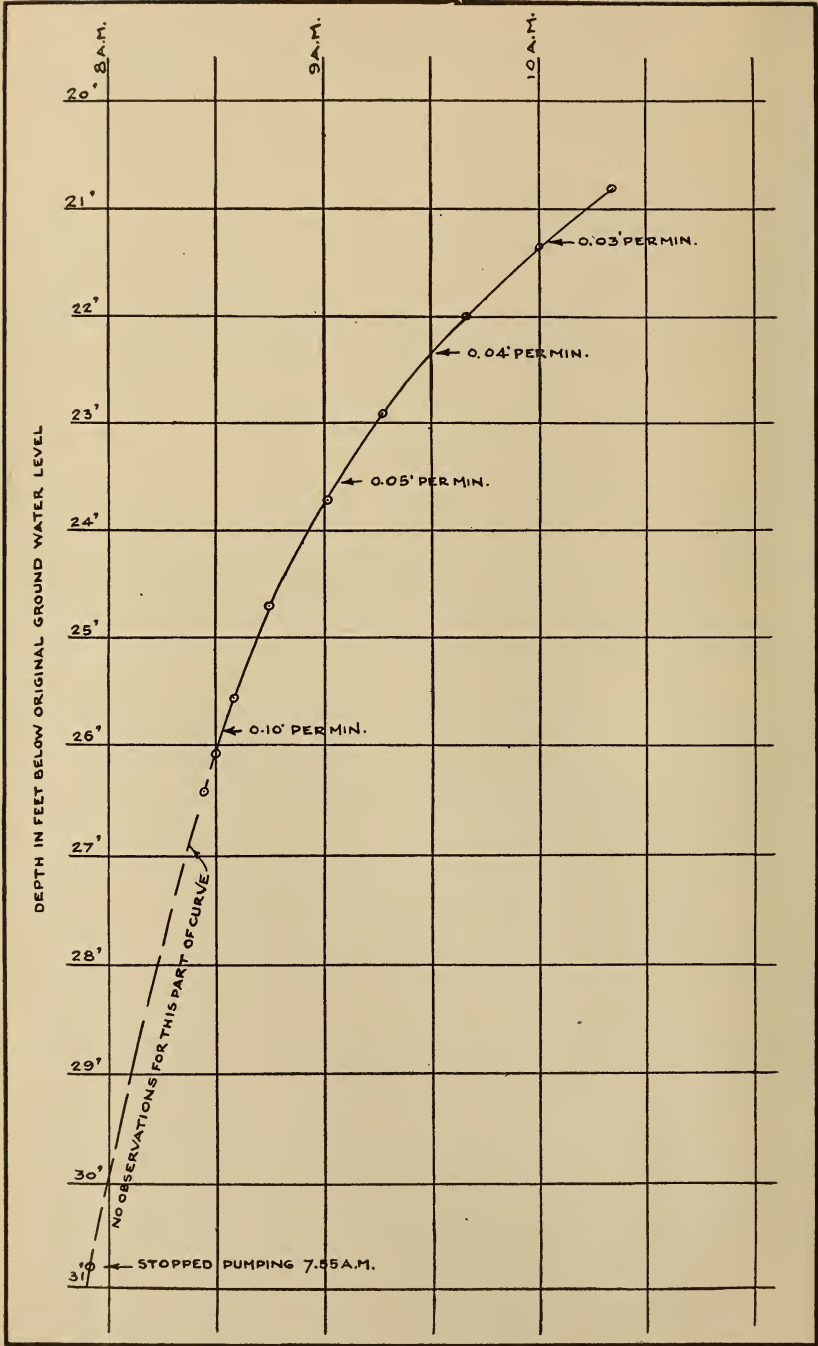


Fig. 25 Curve showing rate of rise of ground water — after pumping — hole 34

three days after pumping ceased water rose 5.2 feet, and in 22 days rose 9.8 feet or at the rate of 0.45 feet per day.

During construction¹ shaft 4 located at same point as hole 32/22, station 607 + 50, has proved a very wet shaft, the inflow varying from 400 to 850 gallons per minute. Pumping at this shaft has lowered the general water level and correspondingly lowered the water level in hole 34/22 at station 600 + 00.

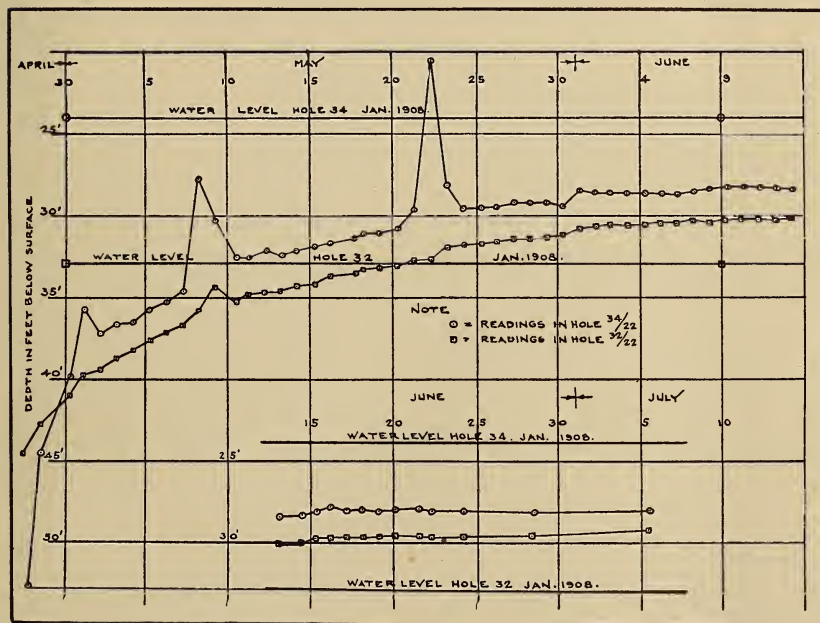


Fig. 26 Curve showing rise of water in holes 32 and 34 after pumping ceased in hole 34

¹ From this shaft after reaching tunnel grade,—250 feet, and after running northward into the fault zone and porous shales, the contractors are pumping 1300 gallons per minute.

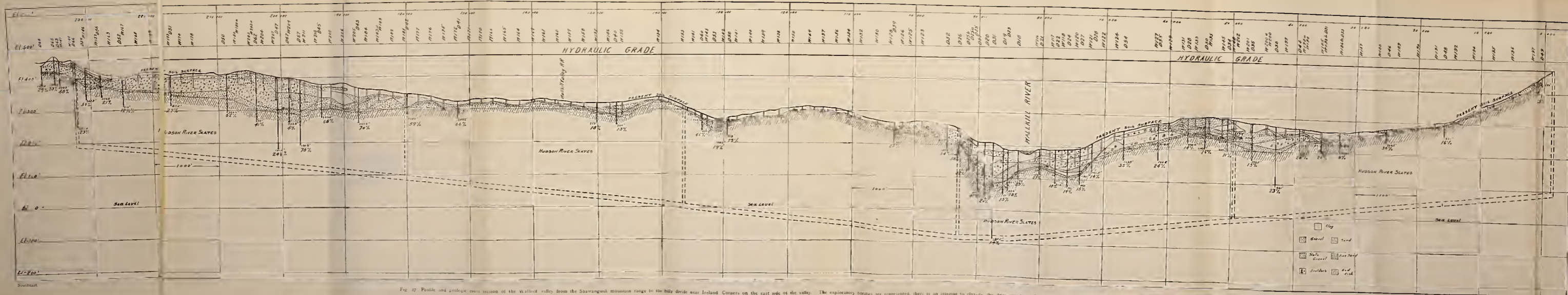


Fig. 27. Profile and geologic cross section of the Walkkill valley from the Shawangunk mountain range to the billy divide near Ireland Corners on the east side of the valley. The exploratory borings are represented, there is an attempt to classify the drift variety, and the approximate position of the pressure tunnel to be constructed for the Catskill aqueduct is indicated. (Adapted from drawings of the Board of Water Supply)

KEY MAP

CHAPTER VII

THE WALLKILL VALLEY SECTION

Between the Rondout and Wallkill valleys the aqueduct is to follow a tunnel at hydraulic grade which so far as can be seen will cut only Shawangunk conglomerate and Hudson River slates. No doubt there are many complicated small structures which because of the nature of the slates can not be reconstructed. The work of tunneling is not advanced far enough to add anything. But in the Wallkill valley, where it is necessary again to plan a pressure tunnel several hundred feet below grade, a considerable amount of exploration has been carried on.¹

These explorations [*see* sketch map fig. 8] are distributed along several lines crossing the valley at intervals between Springtown, about 3 miles north of New Paltz, and Libertyville, which is about an equal distance south.

The geology is simple. Only Hudson River slates form the rock floor, and so far as can be judged no other formation is likely to be cut by the tunnels. There are no doubt many complicated structures, both folds and faults, as indicated by the high dips, but again because of the nature of this rock it is impossible to discriminate closely enough between different beds to determine exact relations. The point of greatest practical importance lies in the fact that the rock is fairly uniform and, although much disturbed is of such nature that crevices and joints or fault zones are almost as impervious as the undisturbed rock. This is because of the tendency of a formation of this composition to heal itself with fine, compact clay gouge. In fact, the mechanical disturbance produces or develops the cement filling contemporaneously with the movement. It is chiefly a mechanical filling, whereas the healing of a harder and more brittle rock like a granite or a limestone requires more chemical assistance.

An additional practical question involves the estimate of depth required to avoid any possible buried Prepleistocene gorges and maintain a safe cover to guard against undue leakage or rupture.

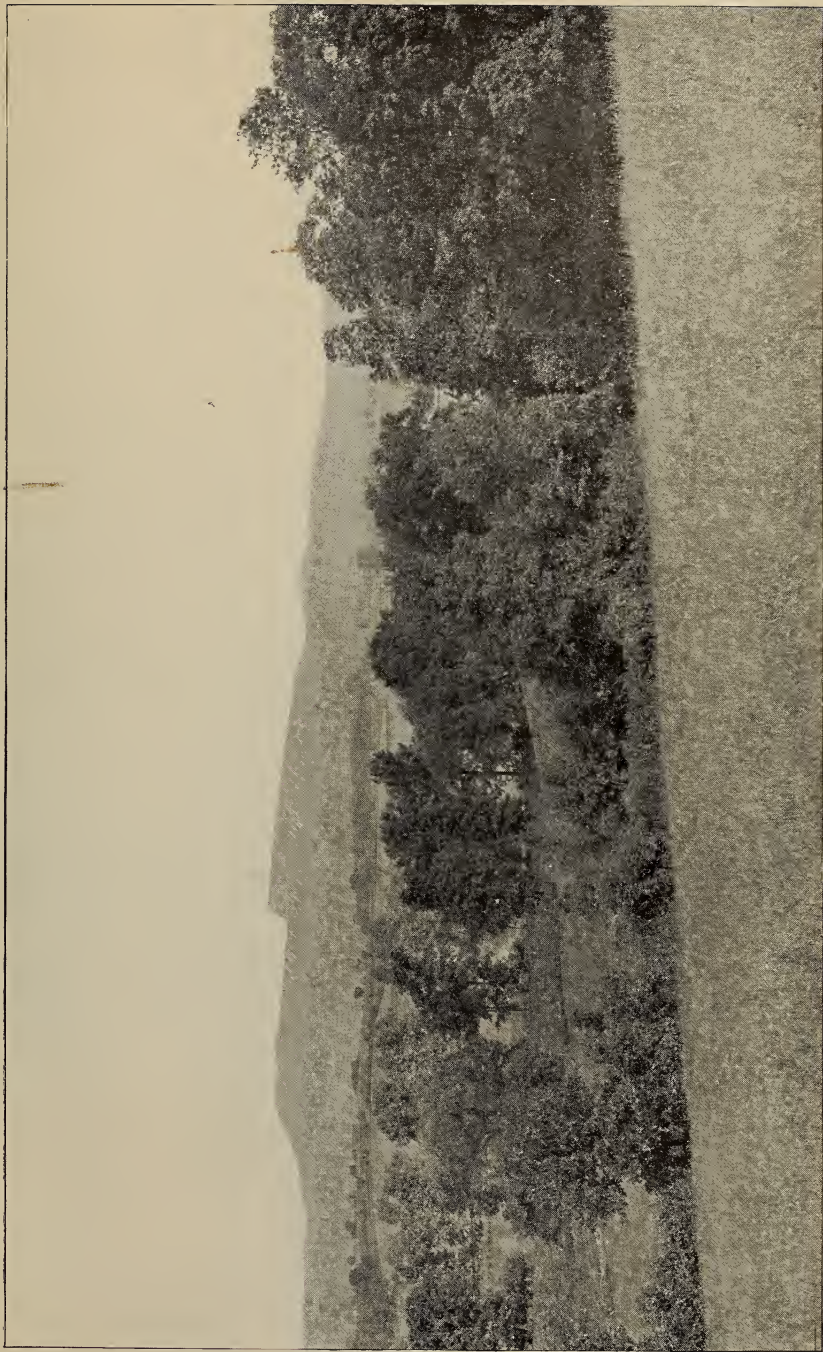
¹ Explorations on the Wallkill division are carried on under the direction of Lawrence C. Brink, division engineer. The final construction is in charge of James F. Sanborn, division engineer, with headquarters at New Paltz, N. Y.

To this end most of the explorations were made. Two lines less than a mile apart on which a few exploratory borings were made near Springtown indicate two buried channels, a master channel and a tributary from the west which converge northward. A maximum depth reaching 70 feet below sea level was found on the more northerly line almost directly beneath the present stream channel which flows on drift at an elevation of 150 above tide.

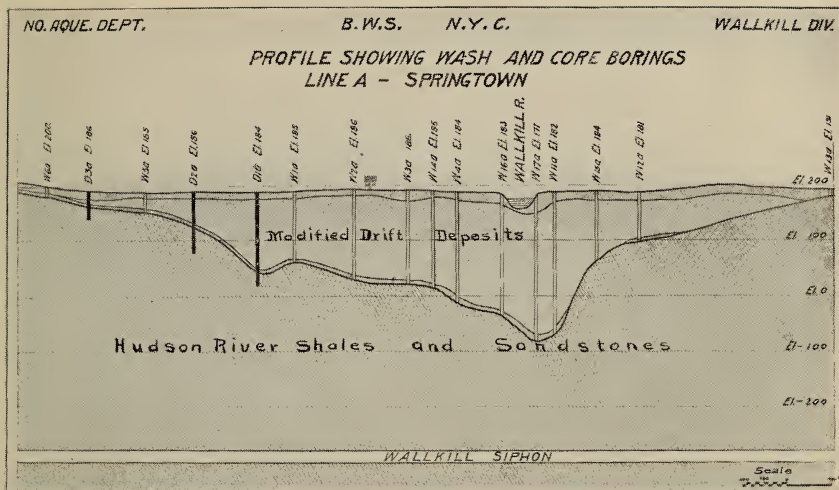
The more southerly profile reaches only sea level indicating a gradient for the preglacial stream at this immediate locality of more than 79 feet per mile.

In the vicinity of Libertyville, 5 to 6 miles farther south, where the aqueduct was finally located, the profile was found to be considerably higher. Intermediate profiles are shown in accompanying figures. The deepest point yet found on the Libertyville line is 65 feet above sea level. It is worth noting that the gradient of the ancient Wallkill is therefore shown to be decidedly unsymmetrical. The rock floor formation remains the same although it may vary somewhat in character. Under these circumstances, however, a gradient of 13 feet per mile from Libertyville to Springtown forms a sharp contrast with the 79 feet per mile represented at the Springtown locality. In view of the remarkable increase of gradient and the narrower form it seems reasonable to regard this as a rejuvenation feature developed at the time of extreme continental elevation.

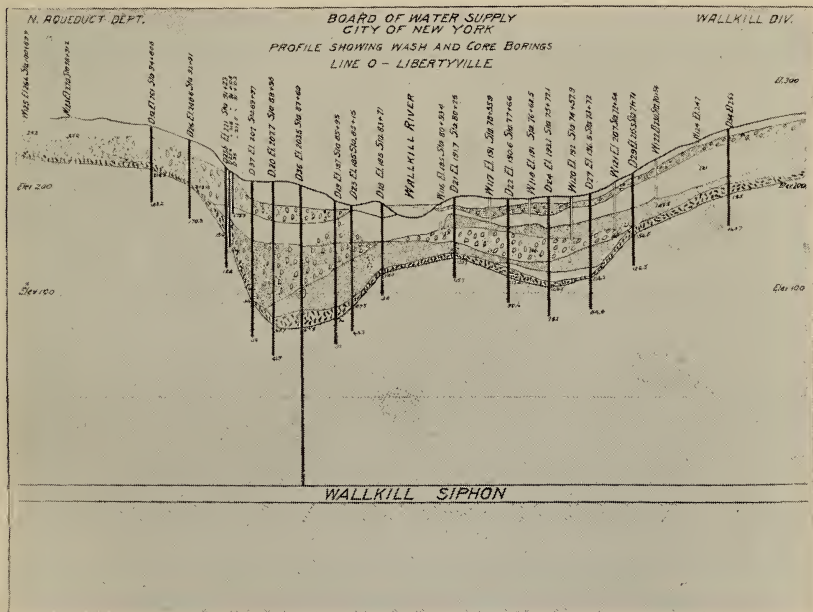
How much deeper the lower Wallkill may be, including the so called Rondout river, which is really a continuation of the ancient Wallkill and geologically belongs to this drainage line instead of to the Rondout, no one can tell. But it is at least interesting to observe that the intervening distance from Springtown to the Hudson at Kingston is approximately 12 miles and that a gradient for that distance equal to the average known in the 6 miles explored, i. e. 24 feet per mile, would depress the outlet 288 feet more. That would be equivalent to 367 feet below sea level. If, however, a steep gradient such as that at Springtown prevails in this lower portion it is necessarily much lower—for example if a 79 foot gradient is maintained it would be possible to reach a final outlet at —1029 feet. It is likely that an intermediate value is more nearly correct. This has, however, an important bearing upon the question of maximum Hudson river depth, especially the existence of an inner deeper gorge above the Highlands. So far as this Wallkill profile goes, it supports the gorge theory. It is certain that the Prepleistocene Wallkill flowed north not very dif-



The Wallkill valley looking toward Bronticou Crag in the Shawangunk mountain range. (Photograph by Board of Water Supply)



Cross section showing the buried preglacial Walkkill channel as indicated by exploratory borings near Springtown



Profiles of the present and preglacial Walkkill channels near Libertyville, and a diagrammatic section showing the different types of drift-filling together with the borings which furnished the data

ferently from the present stream except on a steeper gradient, but in all probability the headwater supplies between this stream and the Moodna have been somewhat shifted. It is possible that some former Moodna drainage area is now tributary to the Wallkill. But these changes were wholly glacial in origin and the extent of such shift is indeterminate at present.

It is a notable fact that a large proportion of the work of exploration in this valley was done successfully by the wash rig.

The extensive lot of data was gathered without much delay or difficulty. This is because of the nature and origin of the drift cover. A considerable proportion of the drift mantle especially in central and deeper portion of the valley is modified assorted sands, gravels and silts or muds. In part they represent deposits in standing water laid down at a time when the lower (north) end of the valley was obstructed by ice and while waste was poured into the valley from neighboring ice fields. It is impossible to reconstruct the beds of these materials with any degree of accuracy. But it is at least certain that lens or wedgelike layers of different quality of material were penetrated, indicating oscillation and overlapping of deposition conditions, boulder beds and till being interlocked with assorted sands and gravels. But there is apparently no evidence of ice deposits of greatly differing age. The accompanying profile and cross section is a representation of materials on the Libertyville line based upon identifications made by the inspector of the Board of Water Supply of the Wallkill Division under Mr L. C. Brink, division engineer.

CHAPTER VIII

ANCIENT MOODNA VALLEY

Moodna creek enters the Hudson from the west between Cornwall and Newburgh not more than a mile north of the entrance to the Highlands. It is a retrograde stream in its backward flow similar to the Wallkill. But its channel at present is almost wholly on glacial drift which it has trenched to a depth of more than 100 feet below the average adjacent surface. How much of its retrograde course therefore may be postglacial is not so clear. It seems necessary, however, to account for all drainage on the north margin of the Highlands by streams flowing to the Hudson northward. There is no notch low enough for their escape elsewhere. The ancient Moodna must have carried most of this run-off from the district occupying the angle between the Wallkill and the Highlands. This stream may have drained even more of the region now forming the divide with the Wallkill than does the present Moodna. In any case it must have been a stream of considerable size, capable of excavating a valley or gorge of greater prominence during the period of early Pleistocene rejuvenation than now appears. Furthermore its position makes it highly probable that tributaries of fair size entering in its lower course were also effective enough to require consideration. This conclusion has led to the exploration of the Moodna valley in considerable detail in preparation for the aqueduct work.

The Catskill aqueduct is to cross the stream near Firth Cliffe, which lies almost directly west of Cornwall-on-Hudson, and because of the low surface elevation across this valley, as in the others, a pressure tunnel in rock is judged to be the most suitable type of structure. The accompanying sketch map shows the location.

Explorations were conducted especially for the buried channels and character of rock floor.

Geologic features

The region is one of chiefly Hudson River slate. But there are inliers of the older rocks such as Snake hill which belongs to a long ridge of Precambrian gneiss and granite, brought to the surface by folding and faulting and there are more rarely outliers of younger formations such as Skunnemunk mountain. Farther north

at Newburgh a gneiss ridge is accompanied by limestone, but in its southerly extension the slates are in direct contact. This relation is believed to be wholly due to faulting on both limbs of the anticlines. This gneiss ridge disappears southward beneath the drift, but the borings have shown that it continues across the aqueduct line, although it has lost its influence on the topography. There are other inliers of similar character such as Cronomer hill 3 miles northwest of Newburgh. Between these two gneiss ridges lies the southerly extension of the Wappinger limestone belt. But so far as is known it disappears beneath the Hudson River series long before reaching the line of exploration.

Near Idlewild station, filling the space between the two branches of the Erie Railroad, there is a syncline containing the series of Siluric and Devonian strata which spreads southwestward to include Skunnemunk mountain, an outlier of Devonian strata. This is the only occurrence of these formations in this region south of the Rondout valley. The structure and stratigraphic features of this occurrence have been worked out by Hartnagel. Its northward extension in all probability terminates abruptly by a cross fault not far north of the Ontario and Western Railroad.

From these occurrences southward to the Highlands proper nearly everything to be seen through the drift is Hudson River slates.

The Highland gneisses are bounded on the north side by a fault or series of faults. This brings various members of the overlying series into contact along the margin. In the best place where a direct observation can be made the gneisses are thrust over upon the Hudson River slates along a plane that dips about 40 degrees to the northeast. It is probable that a displacement of as much as 2000 feet or more could reasonably be assumed at this place. The contact zone also is much crushed and bears every evidence of having undergone extensive disturbance of this kind. Others of this same type occur within the gneisses where weaknesses formed in this way permit the development of such notches as Pagenstechers gorge. In some cases the rock beneath the surface in these zones is more decayed and less substantial than that at the surface.

Exploration

The first borings made with the wash rig were found extremely unreliable in the Moodna valley. That is because of the very heavy bouldery drift forming the greater part of the filling on the ancient topography. Next to the Hudson river gorge itself, no

place has presented greater difficulties in penetrating this drift mantle. Boulders of such immense size occur that they have to be drilled like bed rock. In one of the holes a boulder 30 feet through was penetrated and 100 feet more of drift found below. Progress in such ground is extremely slow and costly. This is so much the more so where as in this case there are long stretches with unusually deep cover.

A glance at the accompanying profile and cross section will show a very deep and wide valley. Many of the borings are more than 300 feet in drift which almost wholly obscures the ancient topography. The present Moodna is about half as deep and occupies the extreme eastern margin of the older gorge. There is a secondary gorge on the west separated from the main channel by a sharp divide. A few other smaller notches in the line represent smaller tributary or independent stream courses. One of these of much interest is known as Pagenstechers gorge.

The rock floor at all points except two in the central Moodna valley including its two nearest tributaries is Hudson River shales, slates and sandstones of considerable variation, sometimes much brecciated. The two exceptional borings are no. 8/A44 and no. 16/A44 on the west flank of the westerly tributary gorge, and they are in pegmatite and granitic gneiss which is in all probability the narrow southerly extension of the Snake hill ridge. Here again neither quartzite nor limestone were found on the flank, a condition that seems to support the view of a double fault along the Snake hill ridge.

In striking contrast with the broad central Moodna are the two narrow and very deep notches farther to the east, the first in slates and the second (Pagenstechers) in Highlands gneiss.

Special features

Course of the Moodna. The chief interest centers around the Moodna channel. There are several unusual conditions, for example:

The rock floor along the profile is almost flat for a distance of nearly half a mile in spite of the fact that there would seem to be every reason for a different form. The differences in hardness of rock floor alone would encourage differential erosion; and, since the structure of the formations, the strike, is almost parallel to the supposed course of the stream, the influence of different beds would be at a maximum. Furthermore, the deep gorge of the Hudson, into which the stream flowed is only 2 miles away;

and if that gorge represents stream erosion to such depth (over 750 feet) it would indicate a gradient of nearly 300 feet to the mile for the last 2 miles of the Moodna — a condition to say the least decidedly unfavorable to the development of a flat-bottomed valley.

Of course, if the profile as determined can be assumed to run exactly parallel to the old stream channel for half a mile it would be less surprising. But even then it is too flat. For so short a distance from the Hudson gorge the gradient ought to be much greater than the variation observed in the Moodna channel. There are certainly reasons in the structural geology favoring a northeast course instead of one parallel to the profile line. And if the stream really did flow across this structure, the differences of hardness of beds ought to have encouraged a much greater difference in depth of channel than the profile presents. With structures all running northeast there is every reason to expect the stream to follow them.

Recent exploratory data strongly supports the theory that the Hudson gorge at Storm King gap is widened and possibly somewhat overdeepened by glacial ice. Under normal stream relations one might consider the Moodna a tributary hanging valley, itself rounded and smoothed to a broad U-shape by ice. This would be a very easy solution if it were not for the fact that this tributary Moodna opens into the Hudson as a reversed stream, i. e. it opens against the flow of the Hudson and more or less directly against the known ice movement. It can not be a hanging valley therefore of the normal sort. If a hanging valley of ice origin at all it would necessarily be one therefore gouged out by ice moving from its mouth toward its head, a case that so far as the writer knows has never been observed. The chief objection to this theory is that in no other gorge or channel (with one exception, the Hudson at Storm King gap) anywhere in the region so far as known is there any evidence of serious modification of an original stream channel by the ice invasion. Of course, the axis of the valley is favorable and the situation is peculiar in that it parallels the Highlands front in this vicinity and the action of the ice may be assumed to have been somewhat concentrated along this margin because of the obstruction.

Inner notch or secondary gorge. Those who habitually emphasize ice action would no doubt choose to regard this whole valley as shown in the profile, as chiefly glacial in character and origin. If that explanation is the true one, then it must be admitted that a deeper smaller inner notch or gorge is unnecessary and indeed unlikely.

The critical point therefore in the whole argument is as to the origin of the valley, i. e. is it essentially a stream valley? Or is it as to present rock floor form wholly a glacial valley?

If it is a stream valley then no doubt full account must be taken of the proximity to the Hudson, and the possibility of developing a temporary graded condition and some adequate allowance must be made for its work during the subsequent continental elevation and the deepening of that river to several hundred feet below the known bottom of the Moodna. In short, one would expect a narrow deeper notch in the Moodna floor as a result of this rejuvenation. But on the contrary if in preglacial time the stream were not so powerful and had not been able to keep pace, and if the ice movement can be assumed to have concentrated along this line to such efficiency as to gouge out a groove 3000 feet wide almost flat to a depth of 300 feet only guided in direction by the original Moodna, then one may readily abandon the idea of a deeper notch.

One or the other of these types of origin must be the chief factor in reaching a reasonable opinion as to the presence of an inner notch.

In any attempt to choose between these factors, one is led to reconstruct the preglacial drainage lines. When this is done it at once appears as most probable that there was at that time as now a considerable area tributary to the Hudson with a stream course very much like the present Moodna. In other words a fair sized stream is assured. Once such a stream is granted and the effects of its work reckoned in full knowledge of the adjacent Hudson, and its probable behavior is studied in the light of the data obtained in exploration of the valleys of other tributaries, it becomes more and more difficult to wholly eliminate the inner gorge idea. It seems to the writer probable that the valley owes its erosion chiefly to the preglacial stream. But the channel has suffered subsequent widening and smoothing by ice especially in its upper and broader portion, below which there may yet be a notch. One must admit that the results of boring prove the notch to be very narrow, less than 150 feet, or else not there at all. In reaching an opinion as to the possibility of one so narrow, it is worth while to note that the Esopus, which is a larger stream, has cut down at Cathedral gorge to a depth of from 50 to 80 feet with almost vertical sides and only about 150 feet wide. This gorge furthermore is cut in almost horizontal strata of such character that there is no special structural tendency in them to contract the stream. At the Moodna on the contrary, in addition to the smaller

size of stream, the rocks stand on edge and run parallel to the supposed course so that this structural influence is toward a narrow and reasonably straight gorgelike form. It is not only possible that the gorge is narrow, but even probable that it is narrower than the present Moodna, i. e. less than 100 feet wide.

How deep such an inner gorge may be if it does exist is a practical question in this particular case, because its depth has a direct influence on choice of depth of pressure tunnel. Because of the evident narrowness it is likely that it is not of very great depth—in view of the quality of these shales perhaps not over a hundred feet.

Is there any one point more than another favorable for such a notch? There are two facts bearing on this question, (1) the variation in core saving which indicates that hole no. 5/A44 with 7% has a recovery of only 1/5 the average, and (2) the fact that hole no. 15/A44+, which is the next hole, shows the lowest bed rock in this valley. On the ground of profile therefore and on the ground of structural weakness there is reason to choose this space between no. 5/A44 and no. 15/A44 as the most likely position.

Summary. The very abnormal profile of the Moodna valley based upon the borings may be due either (1) to parallelism with the stream course, or (2) to a graded condition of the stream in some preglacial epoch, or (3) to modification of an original less prominent channel by ice erosion.

It is the opinion of the writer that the ancient stream crossed the profile line much as the present stream does, that the additional narrower valley immediately to the west side is that of a preglacial tributary instead of a bend of the Moodna itself, that there was a development of a moderate sized somewhat flattened valley corresponding to the benches and shelves noted in other streams, including the Hudson, that subsequent elevation of the continent rejuvenated the stream which cut a deeper narrow inner notch, that glacial ice moving in reverse direction widened and smoothed this upper portion of the valley, but that there may yet be a remnant of the deeper notch in its bottom, and that the space between holes no. 5/A44 and no. 15/A44 is the most likely location of this inner gorge.

Tributary divide. The sharp divide between the two deep portions of the valley bottom has proven an evasive feature in the later exploration. Two holes put down a short distance to the southward (24/A44 and 20/A44) failed to find the rock floor so high, one reaching rock at a depth of 181 feet and the other failing



PROFILE ALONG ...

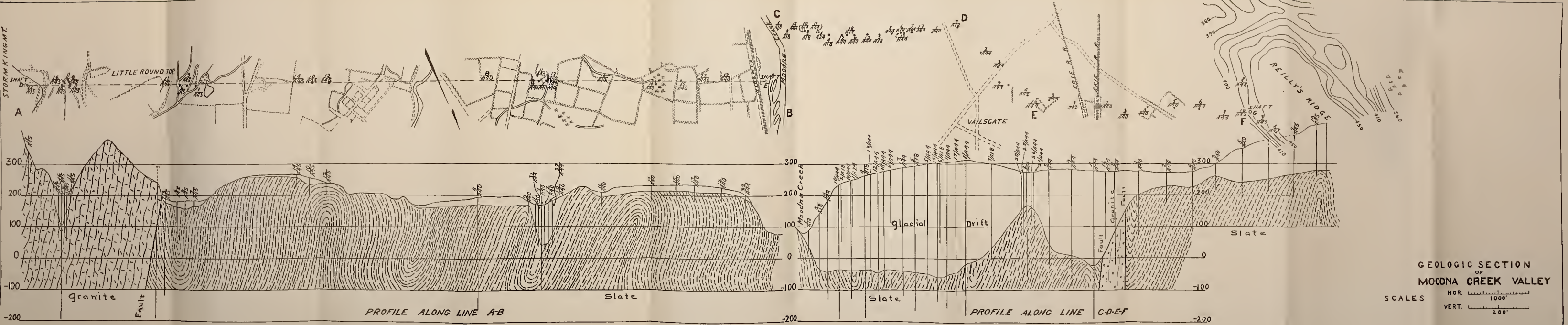


Figure 28

to find rock even at 213 feet. Two others nearly a thousand feet to the westward, however, found rock again at approximately the same elevation as the divide. If this is a tributary stream divide therefore it must have an east-west trend.

Pagenstechers gorge

This is a notch between Storm King ridge and Little Round top occupied by a very small mountain stream. The rock floor is granite gneiss of the Storm King type. Its special characters are (1) extreme shattering or crushed condition, and (2) extensive decay along this zone which has softened the rock constituents to great depth.

Considering the nature of the granite gneiss in general this narrow gorge is a surprisingly deep one. But this is no doubt due to the influence of the decayed crush zone. The drill cores taken from the holes that penetrated the floor at this place are so much altered that, after several months exposure to the air, they can be readily crushed in the hand. Hole no. 16/A45 which is centrally located penetrated to —196 feet. It is in material of this same condition, to at least —100 feet. Similar conditions are proven to the north of the line, shown in the accompanying profile and a rapid increase in depths. From the surface outcrops farther up the gulch it is easy to see that the crushed zone extends in that direction with the strongest lines about s. 70 w. This is doubtless on the strike of the fault lines of the northern border of the range. It is of more than usual interest in showing the depth to which incipient decay has penetrated in these crush zones, and the efficiency of stream erosion along them.

Overthrust fault

The principal fault line follows the margin of the granite gneisses. At the best exposure of it the Hudson River slates are overridden by the gneiss. This represents therefore the cutting out entirely of the Wappinger limestone and the Poughquag quartzite and a part of the slates by the displacement which must amount to at least 2000 feet and probably more. The same relation is indicated by the borings and by the outcrop near the village of Cornwall, but a little limestone is found midway between the two points along the strike of the fault. The strike of the fault averages about n. 65° to 70° e., but locally, at the best exposure, it is only n. 35° e. The dip is southeast at an angle of approximately 45 degrees.

Statistics

Moodna valley

I HOLES BORED UNDER AGREEMENT NO. 18

No. A18	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	KIND OF ROCK
1	86	+27	22	0	Slate and sandstone
(On porosity test with plug at 58 feet deep the loss of water was 6 gallons per minute with pressure of 0-10 pounds per square inch.) Test unsatisfactory because of large hole.					
2	236.5	?	0	0	Slate
3	136.3	36.7	26	0	Slate
(On porosity test with depth to plug 173.5 feet and pressure 0-60 pounds per square inch the loss was 5 gallons per minute.) Test unsatisfactory because of large hole.					
4	259.6	39.4	154.5	75	Slate and sandstone
5	295.5	37.5	129.2	71	Slate and sandstone
6	302.7	?	0	0	Slate
7	297.0	+26	30.7	0	Slate

2 HOLES BORED UNDER AGREEMENT NO. 40

No. A40	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved ¹	KIND OF ROCK
1	276	201	125	0	Slate
2	274.3	228.8	52.5	0	"
3	294.7	257.7	45.3	0	"
4	273.1	222.1	139.7	60	Slate and sandstone
5	347.1	239.1	48.7	0	Slate
6	374.6	250.6	38.0	0	"
7	168.4	40.4	110.1	88	Slate and sandstone
8	188.7	168.2	325	76	Slate and sandstone
9	176.3	164.3	25.5	0	Slate
10	172.3	46.3	26	0	"
11	169.9	98.9	25.5	0	"
12	221.2	208.2	25.5	0	Slate and sandstone
13	226.7	210.7	32.7	0	"
14	226.6	212.6	31.0	0	"
15	230.1	215.1	32.5	0	Slate and sandstone
16	208.3	184.3	32.0	0	Slate
17	169.2	43.2	25.0	0	"

¹In cases which show no recovery of core a method of drilling was employed different from the others and the rock was ground to pieces. Failure to recover core may therefore be no indication of poor rock quality.

3 HOLES BORED UNDER AGREEMENT NO. 44

No. A44	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	KIND OF ROCK
1	313.6	-17.4	167.5	15	Slate and sandstone
2	274.5	+171.5	229.6	20	Slate and sandstone
3	282.7	+39.7	58.8	14	Slate
4	277.8	-22.2	166.7	26	Slate and sandstone
5	299.5	-47.0	50.9	7	Slate and sandstone
6	279.5	-40.3	43.0	27	Slate
7	299.2	-51.6	102.2	27	Slate
8	277.	+89.0	109.3	57.6	Granite gneiss and quartz
9	282.6	+7.6	90.	13	Slate and sandstone
10	230.5	-39.5	154.7	49	Slate and sandstone
11	249.5	-32.5	93.5	11	Slate and sandstone
12	272.0	-45.	58.6	30	Slate and sandstone
13	288.4	-37.6	79.0	13	Slate
14	185.1	-39.9	91.8	32	Slate and sandstone
15	301.8	-59.2	75.	45	Slate and sandstone
16	277.3	+25.9	104.6	43	Pegmatitic granite
17	300.	-42.	75.2	33	Slate and sandstone

¹ Porosity test made on hole no. 1 shows a loss of .03 gallons of water under 100 pounds pressure with packer at depth of 387 feet. Depth to ground water 217 feet.

Porosity test on hole 2/A44.

Ground water level at a depth of 90 feet = el. + 184.5'.

SUMMARY

Depth to packing in feet	0	20	40	60	80	100 = Gage pressure
	40	60	80	100	120	140 = Calculated pressure ¹
146.....	.25	.37	.50	.64	.79	1.03 = gallons lost
196.....	.20	.27	.35	.42	.52	.67 "
247.....	.09	.12	.16	.19	.23	.28 "

¹ Calculated pressure equals average pressure plus weight of column of water from surface to ground water level. Gage pressure is given in pounds per square inch. Loss is in gallons per minute.

4 HOLES BORED UNDER AGREEMENT NO. 45

No. A45	Surface elevation in feet	Rock elevation in feet	Rock penetration in feet	Per cent core saved	KIND OF ROCK
1a	426.2	278.4	19.7	0	Slate with quartz
2	390.5	266.5	76.	0	Slate
3	442.8	286.8	25.5	0	"
4	432.9	268.9	31.	0	"
5	433.	307.5	36.5	0	"
6	180.1	161.8	81.7	53	Slate with quartz
7	179.4	163.4	26.0	0	Slate
8	214.2	142.2	46.5	0	Decayed granite gneiss
9	179.4	151.9	27.5	0	Slate
10	260.1	237.1	34.0	0	"
11	214.6	155.6	95.5	0	Decayed granite gneiss
12	237.6	236.6	35.5	0	Slate
13	182.7	168.6	287.4	48	"
14	269.8	257.3	28.	0	"
15	209.6	130.1	36.1	0	Decayed granite gneiss
16	213.2	11.7	308.3	28	Decayed granite gneiss and seamy gneiss
17	387.6	387.6	163.0	69	Gneiss and dyke rock

CHAPTER IX

ROCK CONDITION AT FOUNDRY BROOK¹

Foundry brook is a small stream entering the Hudson at Cold Spring in the Highlands. It drains a rather abnormally large valley bordering Bull mountain, and Breakneck ridge on the east, and its axis is in the strike of the principal structure of the gneisses which form the chief rock formation of the floor. This valley is in exact line with the course of the Hudson from West Point immediately southward, and its rock formations are similar in character and condition.

There is greater variety of rock composition in this belt, i. e. the Foundry Brook-Hudson river belt, than in any other in the Highlands of similar area. The eastern half of the belt is a typical development of banded gneisses and schists and quartzites belonging to the sedimentary representatives of the Highlands gneiss. Small layers of interbedded limestones are frequent together with serpentine, and mica and graphite and quartz schists. In addition along the east bank of the Hudson, they are profoundly modified by crushing and shearing in zones that trend with the formation, i. e. in a direction leading toward and through Foundry brook valley.

The west side is much less variable and is bounded at the margin by one of the most massive types of the region — the Bull mountain and Breakneck mountain gneissoid granites, which are essentially the same as that of Storm King mountain.

But additional structures enter Foundry brook valley from the western side at an acute angle with its axis and formational trend. These additional structures are two well marked faults, which cross the Hudson — one along the precipitous southeast face of Crows Nest and the other along the southeast face of Storm King mountain. These are the most pronounced escarpments of the whole region. The first one crosses the Hudson between Cold Spring and Bull mountain and in passing northeastward loses much of its influence upon topography and its movement is probably dissipated in that direction. A line from the southeastern face of Crows Nest to the point to be described runs n. 50° e.

¹ Explorations at Foundry brook were done under the direction of Mr William E. Swift, division engineer, now in charge of the Hudson River division of the Northern aqueduct.

Explorations

Foundry brook therefore contains structures that could produce considerable effect upon the quality and condition of rock floor. The rock floor is covered with heavy bouldery drift—thicker on the Bull mountain flank than in the valley bottom proper. Where the aqueduct line crosses the floor is at an elevation of 200 feet to 350 feet A. T. Hydraulic grade of the aqueduct is about 400 feet.

The lowest bed rock found along the line is 182.3 feet and the channel of the present stream coincides with the preglacial one in that portion of its course. There are two secondary channels—probably tributary stream channels on the west side. One of these lies under 70–80 feet of drift.

Borings were made for the purpose of determining the rock floor profile and the condition of bed rock. In most of them the ordinary gneisses and granites were penetrated in normal condition.

But in a few a very unusual condition was found. Hole no. 2 at el. 347 feet near the west or Bull mountain margin penetrated 49 feet of drift to el. 298. Then the drill passed into gneiss which was at the top, the first 30 feet, of a fair quality. This is shown by the core recovered—the first 12 feet recovering over 50%. But the percentage of recovery rapidly fell off—amounting to only 36% in the first 50 feet. Only 1 foot of core was recovered in the next 30 feet, or only 3%. While from that point el. 220 feet to the bottom of the hole el. 51.8, at a depth of 295.7 feet from the surface, nothing but fine decomposed matter was washed up. There was no core at all. This was at first reported as sand by the drillmen, and, coming at a time when exploration of deep buried gorges was the rule at other points of the aqueduct, there were many questions about the interpretation of this new hole, the first assumption of the drillers being that an overhanging ledge of a very deep gorge had been penetrated passing through it into river sands below. A little study of the material proved that this view is untenable. The sandy wash from the drill is true disintegrated gneiss much decayed and dislodged by the drill.

But the meaning of it and the extent of it are after all important additional questions.

Interpretation and further explorations

It is certain that the soft material and the “sand” reported from this boring represent rock decay induced by underground water circulation. Water circulation is rather free as is shown by the

fact that there was an artesian flow from this hole of 10 gallons per minute after reaching a depth of 80 feet, which increased to 15 gallons per minute after reaching a depth of 253 feet. This underground supply is maintained since completion and the pressure is sufficient to raise the water about 15 feet above the surface.

This is a behavior that is consistent with the geologic conditions. The boring has no doubt penetrated a crush zone following one of the faults which enters this side of the valley. The crush zone dips steeply and the boring has penetrated the hanging wall of more solid rock in the first 50 feet and, after reaching the broken and decayed portion of the zone, has swung off parallel to the dip and avoiding the more resistant foot wall has followed down on the soft inner streak.

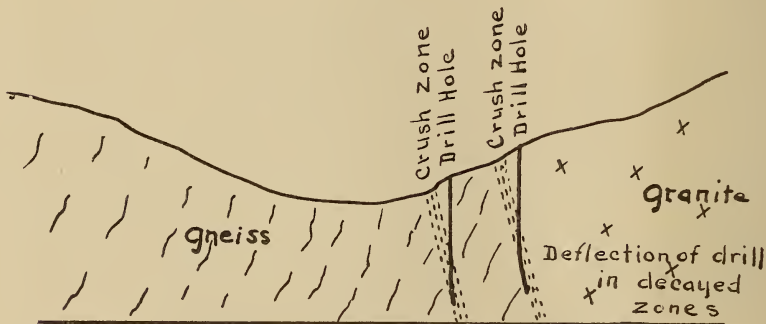


Fig. 30 Sketch illustrating the interpretation of geologic structure across Foundry brook valley indicating the relation of certain borings to them and their supposed influence in deflecting the drills

This crush zone extends on northeastward across higher ground where opportunity for taking in surface water is offered. This is without doubt the source of supply for the circulation which furnishes the artesian flow and which has been so effective in producing decay to great depth. But the circulation and associated decay are probably limited to comparatively narrow zones. There is no good reason for assuming large masses of rotten gneiss at great depth. The worst zones are narrow but may be comparatively deep, i. e. they may extend much deeper than any of the borings yet made in this valley. The depth of decay is related to the outlet for underground circulation which in this case is the gorge of the Hudson.

Several other borings encountered similar conditions, especially those on the west flank of the valley within range of the belt in which the fault seems to be located.

Hole no. 9 reached the rock floor at a depth of 80 feet, and then penetrated rock to a depth of 159.7 feet. All of the material is badly decayed. Only 1 foot of core was recovered from the whole boring and that is mostly quartz coming from a veinlet or pegmatitic streak at 141 feet. Water under slight pressure was encountered in this hole also. But because of the somewhat greater elevation of the surface at this than at hole no. 2 there is not a constant outflow.

Two other holes immediately to the west show much better rock condition — no. 1 showing 79% core recovery. Also two on the east side at greater distance [see accompanying profile] show good rock. But one other no. 3 at a distance of over a thousand feet to the east encountered another zone of decayed rock, the record being very similar to no. 2 in that poorer conditions are shown at depth than near the surface. Rock was found at a depth of 20.2 feet. From 20.2 to 116 feet the gneiss was quite hard, 55.3 feet of core being recovered or 57.7%. But from 116 feet to the bottom 207.5 feet the material was as bad as in hole no. 2, and no core was recovered.

Several other tests were made on the borings with a view to determining the character and extent of these features more definitely. For example, if the interpretation given for the behavior of no. 2 and no. 3 is correct it ought to be possible to survey the holes and determine a deflection from the vertical as the drill deviated from its course to follow the softest streak. A survey conducted for this purpose indicates just such a result. The accompanying sketch shows the data plotted. The drill was deflected $4^{\circ} 36'$ at a depth of 50 feet, $7^{\circ} 36'$ at 100 feet, $8^{\circ} 2'$ at 150 feet and $9^{\circ} 40'$ at 198 feet.

Pressure tests were made for porosity on some of the holes in sound rock. Some of these data are given on the profile.

Some of the rock of this valley, if very extensive, such as that in borings no. 2, no. 3 and no. 9, would be very poor ground for tunneling. The practical question involves especially the width of these zones, are they a foot wide or are they a hundred? In an attempt to help settle that question an inclined hole was proposed that was to run at an angle low enough to crosscut these belts. Accordingly hole no. 14 was bored inclined $40^{\circ} 26'$ to the horizontal and started on the solid granite gneiss. The results were not

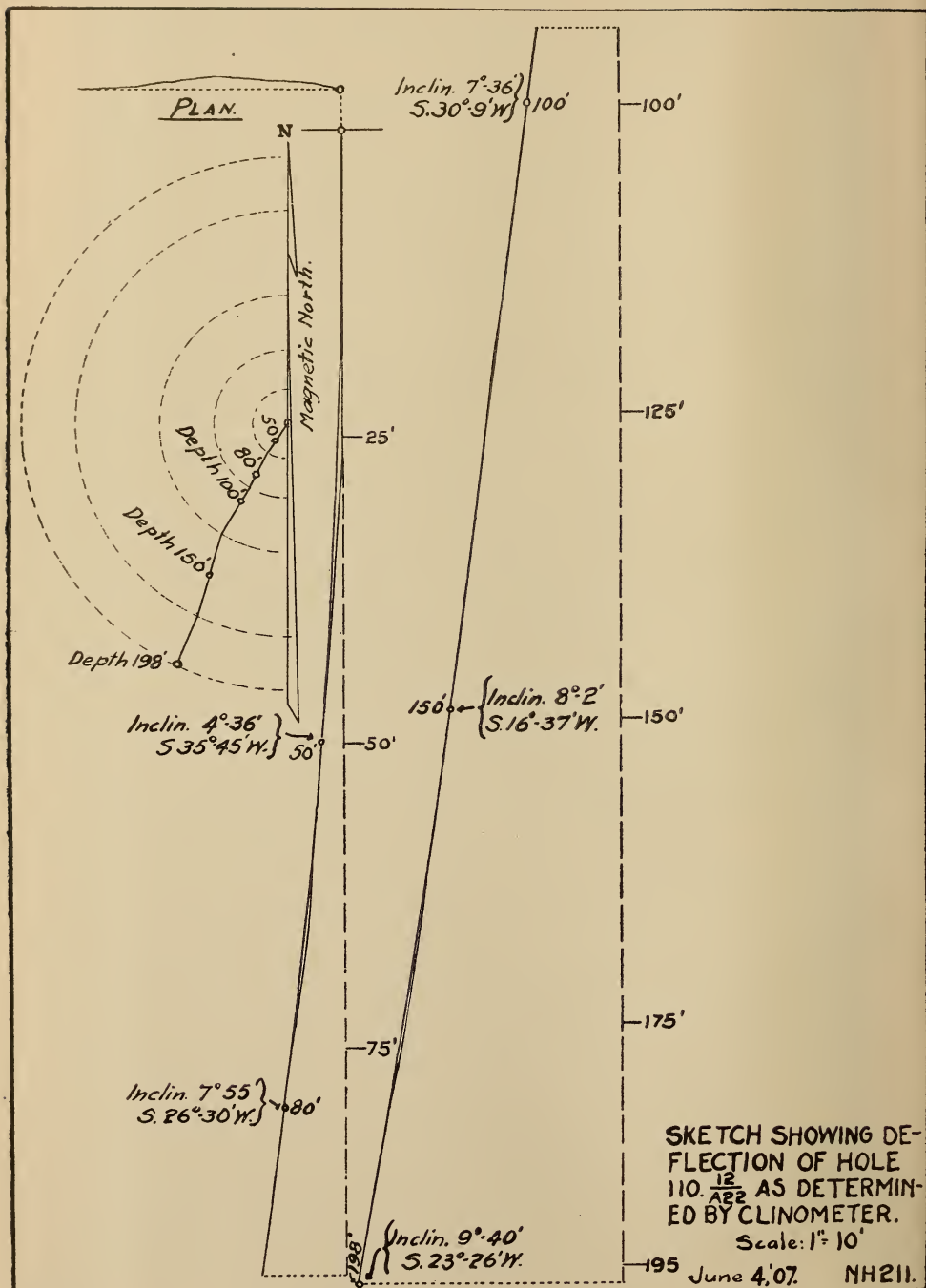


Figure 31

very encouraging. The decay is shown not to be confined to mere seams. The doubt raised by so much bad ground has finally led to the adoption of a different plan for crossing Foundry brook valley and no further data are likely to be added by this work. As it now stands the borings at Foundry brook indicate the deepest decay of any yet made in granites or gneisses except those of Pagenstechers gorge on the north side of Storm King mountain. Both cases are of similar origin and history, but Foundry brook is apparently the more complex in occurrence. There are several parallel zones along which there is extensive decay to a depth of more than 300 feet.

CHAPTER X

GEOLOGY OF SPROUT BROOK

Three creeks unite to form an inlet at the sharp bend in the Hudson immediately above Peekskill. The middle one of these is known as Sprout brook. It occupies a deep and narrow valley that is well marked for 10 miles in its lower course and is traceable as a physiographic feature of less prominence to the north margin of the Highlands. Its persistence indicates some important structural control in erosion.

Geology

This valley lies in the midst of the most typical gneisses and granites of the Highlands region. And in addition several of the "iron mines" of Putnam county lie on its western flank. The rocks are complex granitic and quartzose gneisses and granites. Foliation and banding and bedding wherever this appears is parallel to the axis of the valley. The most notable geologic feature is the occurrence of a broad belt of crystalline limestone throughout the lower 4 miles. It is undoubtedly chiefly this limestone, which is less resistant to weather than the gneisses, that controls the form and size of the valley. As to geologic relations, this is one of the most interesting formations of the region. It is coarsely crystalline, full of silicious impurities at many places and carries small igneous injections and dykes, and so far as the bedding can be followed, stands almost on edge. Although an actual contact is not seen, at several places the limestone and gneiss approach within a few feet of each other and it is certain that no other formation can come between them. This is more certainly indicated in the northerly extension of the valley where the limestone gradually disappears leaving only the gneisses and granites. That there may be a fault contact must be admitted, but of this there is no good evidence in the field.

Such relations and character show that this limestone is similar to the smaller interbedded occurrences noted frequently with the gneisses in the Highlands and elsewhere. If it is of that type then it is the largest representative yet found in that series. But it is also in these characters similar to the Inwood limestone of more southerly areas. The overlying Manhattan schist which is lacking

may have been removed in erosion. One of these types it resembles, but it can not be the Wappinger (Cambro-Ordovician) as was pointed out by the writer in a former report.¹ The Wappinger, wherever known to be such, is never intruded and always lies above a thick quartzite (Poughquag). It does so even in the next valley (Peekskill creek) less than a mile distant. With the interpretation of this Sprout Brook limestone therefore is involved the correlation and interpretation of the age of much greater areas. That the Sprout Brook limestone is not Wappinger is clear enough, but it could be either interbedded (Grenville) or Inwood. If it is Grenville then of course it has no direct bearing on the Wappinger-Inwood question and these two might be equivalents. But if the Sprout Brook limestone is not Grenville (interbedded) then it must be Inwood and in that case the Inwood and Wappinger are not equivalent—which means that there are two series above the gneisses instead of one—an Inwood-Manhattan series, and a Poughquag-Wappinger-Hudson River series. At the present time it is not possible to give with certainty a final interpretation of the Sprout Brook limestone.

Explorations²

It was at first believed that a pressure tunnel could be constructed advantageously at the point of crossing this valley and borings were made to test rock conditions. The data gathered in exploration are indicated on the accompanying geologic cross section [fig. 32].

Borings indicate that the rock floor has been eroded to a few feet below present sea level and that the gorge has a drift filling of more than 150 feet. The central borings penetrate limestone and indicate a total width of this type of more than 400 and less than 600 feet. The best estimate on the basis of these explorations is 500 feet. Whether this width represents one thickness of the formation as would probably be the case if it is an interbedded Grenville layer, or part of a double thickness due to infolding, as would probably be the case if it is the Inwood, there is no evidence. The thickness seems to be even greater farther south in the same valley (it becomes $\frac{1}{4}$ mile wide), but it can not be

¹ Structural and Stratigraphic Features of the Basal Gneisses of the Highlands. N. Y. State Mus. Bul. 107 (1907). p. 361-78.

² Explorations at Sprout brook are in charge of Mr. A. A. Sproul, division engineer in charge of the Peekskill division.

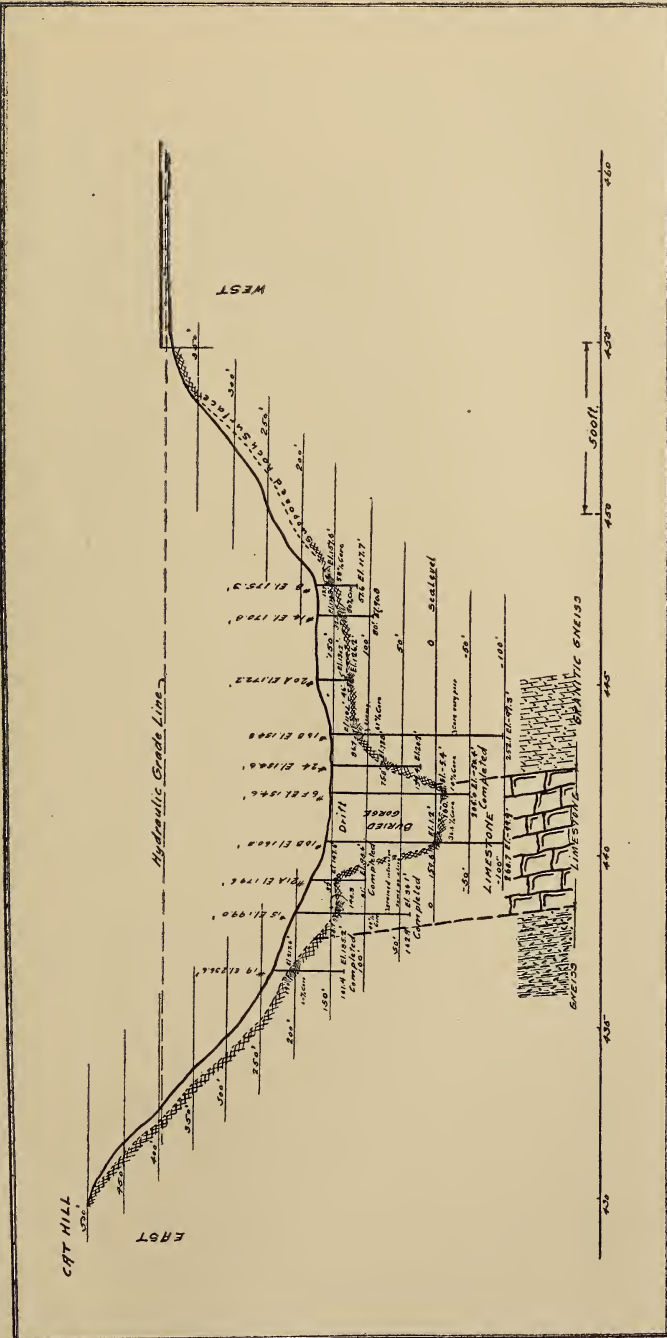


Fig. 32 Geologic cross section of Sprout brook as indicated by the exploratory borings of the Catskill aqueduct

accurately measured and there is no way of guarding against repetition of folds. The valley floor is decidedly terraced at an elevation of about 130 A.T. One side is limestone and the other is granitic rock. This is probably a local mark of the Tertiary base leveling work.

Because of the great depth of this narrow gorge, it would require a 500 foot shaft at each side to lead from hydraulic grade down to a safe level for the pressure tunnel. For a crossing not more than 2000 feet long this is excessive and the cost becomes greater than by other methods of construction. Consequently the tunnel plan has been abandoned and it is not likely that further data bearing upon these questions will be added.

CHAPTER XI

STRUCTURE OF PEEKSKILL CREEK VALLEY

Immediately east of Sprout brook, described in the previous section, is Peekskill creek, which drains the largest valley emerging from the southern margin of the Highlands. This valley as a physiographic feature is continuous with the Hudson river gorge from the sharp bend at Peekskill to Tompkins Cove. There are important structural features along the strike of this valley which extend very far beyond the limits of Peekskill creek itself, among which are strong folding and block faulting. The chief fault continues to the southwest with still greater prominence and appears on the west side of the Hudson in the escarpment forming the southeastern margin of the Highlands continuously for many miles into New Jersey.

Near the Hudson, Peekskill creek and Sprout brook unite and the structures and formations characteristic of each valley converge until in the last half mile of their united course rock formations characteristic of Sprout brook lie on one side of the valley, those characteristic of Peekskill creek on the other, and the contact which follows the divide to that point then passes beneath the waters of Peekskill inlet. Because of the block faulting which has carried down overlying formations and protected them from the total destruction characteristic of the central Highlands region this valley is of unusual interest.

Explorations¹

The aqueduct line crosses this valley about 3 miles from the Hudson, and in determining the possibility of crossing by pressure tunnel in rock a considerable number of explorations were made.

Enough has been done to outline the rock floor profile very definitely and to determine the condition of the formations.

An examination of the drill cores and records of explorations shows the following facts which are compiled as fully as possible on the accompanying cross section.

Phyllite. One boring (no. 1) is in a phyllite whose character and relation to other formations leads to the conclusion that it

¹These explorations were directed by Mr A. A. Sproul, division engineer of the Peekskill division with headquarters at Peekskill, N. Y.

belongs to the Hudson River slate series. This type of rock forms the whole western side of the valley for several miles. Beds stand on edge or dip steeply southeastward and are in good sound physical condition. The rock is everywhere a fine grained micaceous slate or phyllite and in some places carries pyrite crystals. It is impossible to estimate the thickness or minor structural habits. But it is clear that it forms the upper member of a series that has a synclinal structure and therefore the belt represented by the phyllite marks the axis of the syncline although the chief valley development lies wholly to one side.

Limestone. Eleven borings (no. 2, 3 D, 4 C, 11, 13 C, 18, 22, 23, 25, 26 and 29) are in limestone. All show essentially a very fine grained close textured crystalline gray or white or bluish rock with strong bedding standing nearly vertical or at very high angles. This, because of its character and relation to other formations, is regarded as the Wappinger limestone—a formation well known north of the Highlands, where it is at least 1000 feet thick. From present explorations it is now certain that a belt 3250 feet wide is underlain continuously by this formation standing nearly on edge. Unless repeated of course this would represent approximately the thickness for Peekskill valley. But it is not believed to be so thick. It is more likely that there is a threefold occurrence brought about by close isoclinal folding (a closed s-fold) as seen in the accompanying cross section. This view is supported by at least one occurrence of the underlying quartzite member near the center of the valley at a point a couple of miles farther north. On the line of exploration, however, none of the borings penetrate any other formation beneath. Attention is called to additional structural details and physical conditions in a later paragraph.

Quartzite. One boring (no. 5) is in a quartzite. It is very pure, fine grained, closely bound and typical quartzite. The beds stand almost vertical and the whole thickness is known from nearby outcrops to be approximately 600 feet. From its character and relations to other formations it is regarded as the Poughquag—a well known formation of the north side of the Highlands.

Gneisses. Five borings (no. 7 E, 9 B, 17, 27 and 28) are in gneisses. These are to a considerable extent simple granite gneisses of igneous origin. But there is the usual variety characteristic of the Highlands gneisses and no doubt they are representatives of the great basal gneiss series that is elsewhere referred to as the equivalent of the Fordham of New York city.

2 Stratigraphy

This is therefore the rock series of Peekskill creek. It is the only locality on the south side of the Highlands where all are represented in complete and simple form. There is no doubt that it is the Poughquag-Wappinger-Hudson River series, in spite of the complete absence of organic evidence. A similar though not so complete and clear occurrence is to be found on the west side of the Hudson near Stony Point and Tompkins Cove. That is a part of the same structural syncline. It is probable also that the phyllite so finely developed in the village of Peekskill in the next small valley to the east is the same. But outside of these occurrences there are none that clearly represent this same series as a whole and in the same condition.

No more striking example of this fact can be found than the adjacent Sprout brook described in an earlier section. There coarse crystalline and injected and impure limestone occurs alone—no phyllite and no quartzite. When one remembers that the two occurrences so strongly contrasted, Sprout brook and Peekskill creek, converge until they actually unite, and still preserve their stratigraphic dissimilarity, without any adequate structural reason for it, the only conclusion possible is that the two occurrences represent two entirely different series of formations.

The Peekskill valley series is Cambro-Ordovician in age; what is the other? It is older, at least that is certain. But is it (the Sprout Brook limestone) as old as the oldest of the gneisses themselves and therefore interbedded with them representing locally the Grenville; or is it intermediate—Postgrenville and Precambrian—with which possibly other occurrences of rocks of similar habit and equally uncertain relations belong?

It is on the general similarity of this occurrence to the Inwood limestone as known throughout Westchester county and New York city that a tentative intermediate series has been recognized. This is the Inwood-Manhattan series. Whether it is in reality a separate older series is not regarded as proven. But for engineering and practical purposes the distinction is a good one and eminently serviceable. Further discussion may better be continued in a different publication.

3 Rock surface

The bed rock surface is pretty well outlined by the borings. A profile based upon them seems to leave no unexplored space of sufficient extent to admit a gorge of great consequence to a lower level

than is already shown in holes no. 1 and no. 11 [*see* profile and cross section, fig. 33]. The elevation indicated by no. 3 D is believed to be misleading because of the use of a drill that was capable of destroying a part of the ledge rock that would usually core. The points believed to be weakened by structural disturbance and therefore most likely to be attended by erosion and stream action are in the vicinity of hole no. 11, near the present creek, and hole no. 25, near Peekskill Hollow road.

4 Buried channels

From the accompanying cross section it will be seen that the drift cover is more than 100 feet thick over large portions of Peekskill valley. The rock floor in the middle of the valley averages approximately 25 feet A.T., while the drift surface except where cut out by stream erosion is at about 125 feet. In the rock floor there are two depressions, the large one wholly within the limestone belt and the smaller following the limestone-phyllite contact. There is not much difference in their depth so far as explored, but there is a possibility of a somewhat deeper notch in each one. The depth to which some of the limestone beds are decayed by underground circulation would lead to the belief that a deeper notch may exist.

The drift cover is chiefly partially assorted sands and gravels in the central portion of the valley, and more of a till on the eastern valley side. It is noteworthy that the present Peekskill creek lies far to one side following closely the phyllite wall.

5 Underground water

Present elevation above sea level is so slight that there is apparently little encouragement of deep underground circulation. But at certain points the rock has been found to be very badly decayed to a great depth—to at least 200 feet below sea level. This is believed to have been accomplished chiefly at a time when the region stood at a higher level. Hole no. 22 is especially notable in this connection. A comparison of the figures of core saving is one of the best lines of evidence on this question. Wherever data are at hand the percentages of saving have been put on the cross section. Hole no. 29, for example, shows a saving of only 11% in the lower 250 feet, reaching a depth of 297 feet below sea level.

The present water table profile is shown on the cross section. A great body of water stands in the assorted sands directly upon bed

rock forming essentially a great reservoir of supply that has ready access to the almost vertical limestone beds. This will give a maximum water supply to holes that penetrate porous or broken portions of bed rock. The attitude of all strata is especially favorable for admitting an almost inexhaustible supply from a considerable drift-covered area within which circulation is probably very rapid.

6 Condition of rock

All strata of this valley stand so nearly on edge that drills actually explore a very limited portion of the whole series of beds. No very great advantage is gained by excessively deep boring because the drill follows necessarily almost the same bed from top to bottom. At best only the immediately adjacent beds are penetrated. This means that much of the total thickness of beds is untouched by present explorations, and must be interpreted on the basis of their general likeness to those more fully determined. The usual succession of beds is known to be quite uniform in quality and locations where they can be studied and there is no reason to expect greater variation here.

Deviations from such normal or uniform conditions are mostly due (*a*) to local development of mica from recrystallization of impurities in the limestone, and (*b*) to crush zones developed in the process of folding and faulting which has broken the rock or weakened it enough to permit a more ready circulation of underground water. Wherever either of these structural conditions prevail, the rock has been excessively decayed, or disintegrated, or sufficiently weakened in its binding matter or its sutures to crumble in the hand or break down to a sand under ordinary boring manipulation. This condition is known to reach to -297 feet. How much deeper is not known. Probably the decay dates back in large part to preglacial continental elevation at which time probably there was more ready deep circulation with possible outlet in the Hudson gorge. This action has been all the more effective by reason of the attitude of the beds. They stand so nearly on edge that they present all their weaknesses of bedding and sedimentation structures to the destructive surface agents. They admit surface water readily and favor abundant underground circulation.

Considerable faulting occurs. The contact between the granite-gneiss and quartzite is a fault contact. Wherever seen this is sound. But a crush zone in limestone lies nearly central in the valley, cut by holes no. 23 and no. 25, where the rock shows a finely brecciated

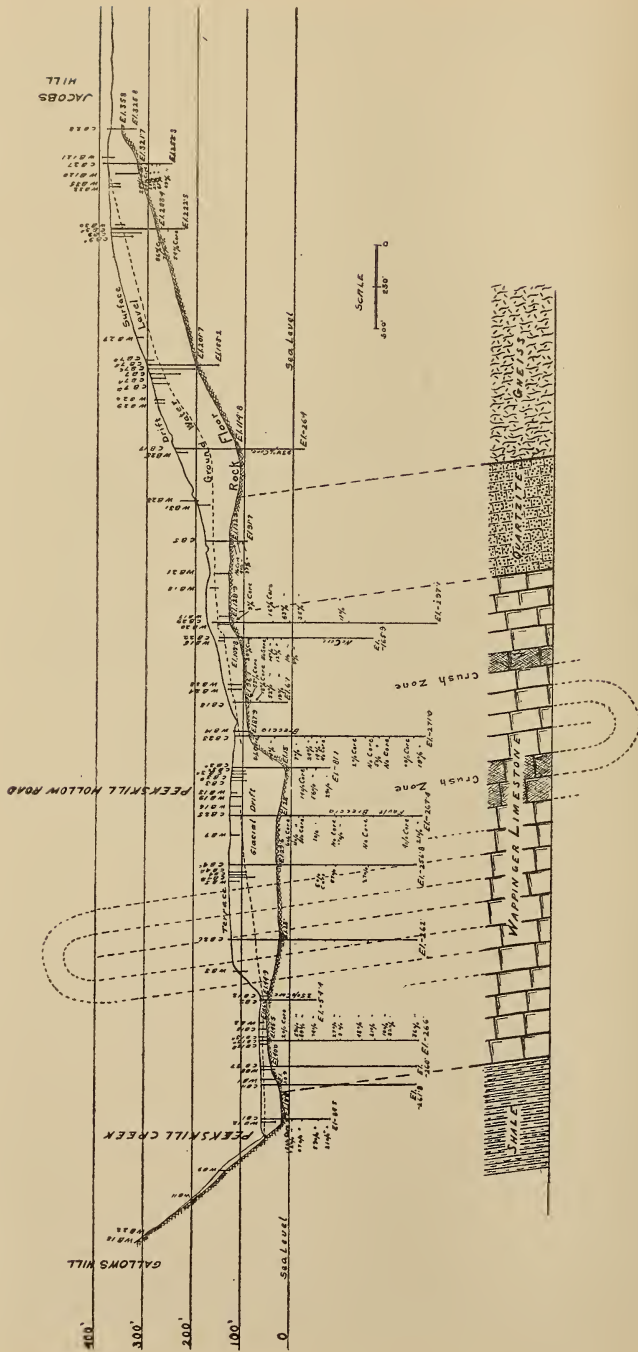


Fig. 33 Geologic cross section and detail of borings across Peekskill valley along the line of the Catskill aqueduct

condition some portions of the drill cores being literally crushed to bits.

In one hole, no. 11, near the phyllite-limestone contact, a soft, sandy condition was encountered at a depth of 133 feet, permitting the drill rods to be pushed down without boring at all, 60 feet ahead of the casing. This, however, is not believed to indicate any very extensive weakness. It is probably connected with the bedding planes or joints rather than with general decay or faulting. Four or five inches of solution and disintegration along bedding planes would account for all that has been proven. The fact that the rods could be shoved down 60 feet while the corresponding outer casing could be shoved down only half as far seems to support this view.

Summary

If a tunnel were made across this valley there would be approximately 1100 feet of it in Hudson River slate (phyllite), 3250 feet in Wappinger limestone, 600 feet in Poughquag quartzite, and the rest in the gneisses.

Some weak rock is certain to be found, especially in the vicinity of station 367+50 and 345+00 to 350+00. At both places increased water inflow would be encountered with almost exhaustless supply from the sands that lie on the rock floor above.

At about this stage in the exploration the Board of Water Supply decided to abandon the rock tunnel plan. The conditions found were considered by them too questionable. Steel pipe construction is to be substituted. As a result it is not likely that much more detail will be added to the structure of this very complex valley.

CHAPTER XII

CROTON LAKE CROSSING

It is proposed to finish Ashokan reservoir and the Northern aqueduct first. This so called Northern aqueduct reaches from the Catskills to Croton lake. Croton lake is the present supply of New York city and is already connected by two aqueducts with the city distribution. As a first step, therefore, and as an emergency measure the Catskill water will be delivered to the Croton system by finishing the Northern aqueduct first. As rapidly, however, as the whole project can be carried out the so called Southern aqueduct will be constructed to continue the Catskill water independently of the Croton supply to the city.

The Southern aqueduct department has charge of the line from Hunters brook on the north side of Croton lake to Hill View reservoir near the New York city boundary. During exploratory work it has been under the direction of Major Merritt H. Smith, department engineer, with headquarters at White Plains. Construction now going on is in charge of Mr F. E. Winsor, department engineer.

The first link in this southerly extension is to be a tunnel beneath Croton lake through which the Catskill water may pass in the same manner as it crosses other valleys. This crossing has been located a short distance below the old dam on the Croton, about 5 miles up stream from the Hudson.

The problems involved at this point include (1) a determination of the kinds and quality of rock to be penetrated, (2) their water-carrying capacity, and (3) opinion as to the proper depth for a successful tunnel.

Geological features

The Croton valley is one of the very few in southeastern New York that actually crosses the geological formations and major structural features instead of following parallel to them. In its lower portion it passes from gneiss to limestone and to schist several times. The reason for this somewhat abnormal course is probably the development of weak zones by fault movements in this transverse direction.

Only one of the well known formations of rock is exposed in the immediate vicinity of the tunnel site. This is the *Manhattan schist*, the uppermost formation of the region south of the Highlands. Along the Croton it varies greatly, the chief type being a

garnet-bearing quartz-mica schist varying from rather fine grain and semigranular appearance to a very coarse and strongly foliated structure. This part of the formation undoubtedly represents recrystallized or metamorphosed sediments. But associated with this facies there is a more dense black hornblende schist that, not only here but at many other places, is thought to represent igneous intrusions that have been metamorphosed together with sediments of various types, until both have lost almost all of their original characters. The hornblendic schist type is not so extensive as the other, the mica schist, but it is more compact and here as usual is in the better condition.

Pegmatite stringers occur abundantly, especially in the mica schist varieties. They are of no great consequence, however, as a factor in this study. They originated in the aqueo-igneous activity involved in the recrystallization of the rock when it was worked over into a schist.

Beneath this Manhattan schist formation lies the *Inwood limestone*, a bed probably at least 700 feet thick. But at this point how deep it lies and at what depth it would be penetrated nobody can tell. None of the drills have touched it. Beneath the limestone in turn lies the granitic and banded gneisses belonging to the *Fordham gneiss series*, the lowest and oldest of the region.

Along the Croton river nothing but Manhattan schist is to be seen at the surface for more than a mile above and below the proposed crossing. The same thing is true for an equal distance on opposite sides from the river at this locality.

But the structure is folded and the normal northeast-southwest trend of the folds crosses the river, every arch or anticline tending to bring the limestone and gneiss nearer to the surface. One of these folds does expose the limestone and gneiss in a strip extending from the Hudson river northeastward for two thirds of the distance to the old Croton dam. But before reaching the Croton valley this fold pitches down toward the northeast beneath the Manhattan schist and passes under the present lake (or reservoir) in that relation, not reaching the surface again for a distance of about 6 miles. At least one more fold is known to behave in a similar manner as it reaches the Croton.

These facts make it certain that there is limestone beneath the schist in the vicinity of the crossing, and that it comes nearer to the surface in that vicinity than at some other places.

South of the Croton there are several small cross faults run-

ning nearly east and west. It is believed that similar movements have affected the rock in the Croton valley itself, modifying its condition so much as to control the course of the stream. The only immediate bearing upon the problem of the Croton crossing is the question that it raises about the quality of rock and the necessity that is introduced of trying to determine whether or not there is shattering enough to be very objectionable.

Explorations and data

Six drill holes have been made on this proposed Croton lake crossing—one on either side just at the margin and four others within the intermediate space of 1400 feet. These inner four have been made from rafts floated on the lake and have penetrated water, drift cover, and rock [*see* accompanying profile and cross section, pl. 27].

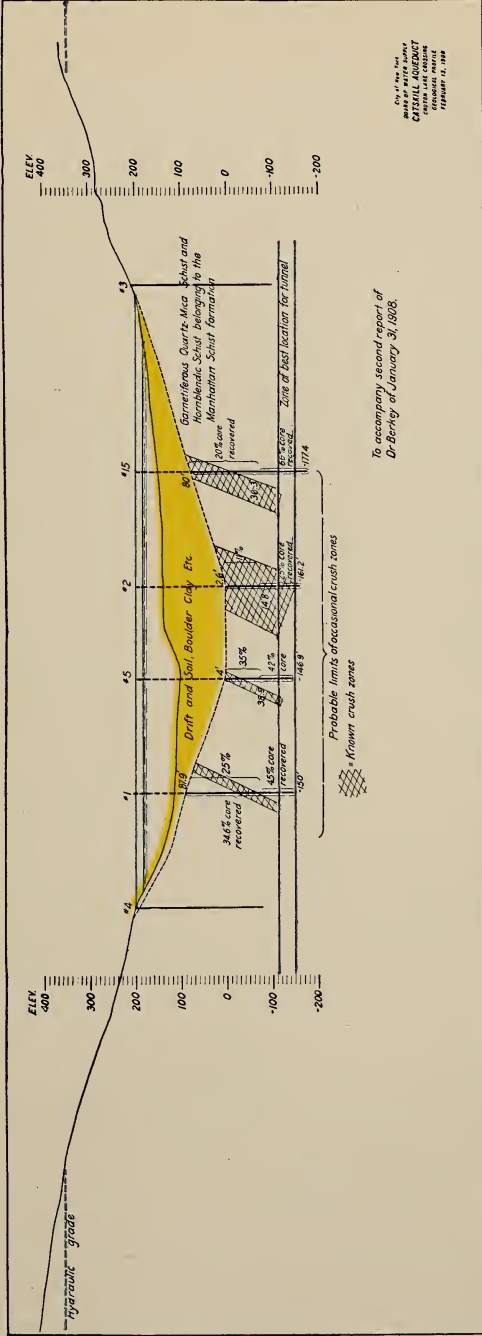
Rock floor. The depth of the preglacial Croton valley is pretty accurately determined at 0 feet or sea level. There is no reason to expect a gorge or inner channel of any consequence.

The drills have penetrated only one formation, i. e. Manhattan schist. These test holes are believed to be near enough together to eliminate the possibility of any other formation appearing at tunnel grade.

Rock condition. The two varieties of schist (1) the coarse garnetiferous quartz-mica rock, which is a metamorphosed former sediment, and (2) the darker, close grained hornblendic rock that is believed to represent an igneous intrusion, both occur in the cores brought up by the drill. Either under normal conditions is a good rock. But there are considerable differences in the physical condition of the rock. Holes no. 3 and no. 4 at the two extremes, on the lake borders, show sound rock that comes up in large cores with very high percentage recovery. This is confidently believed to represent the average condition of the rock in this vicinity at the sides of the valley.

The central holes, however, nos. 1, 2, 5 and 15, all show more broken ground. Of these holes no. 2 is much the most broken, the core recovery being only 14.8%. The pieces are small and many are smoothed (slickensided) by movement. The hole penetrates a typical crush zone resulting from slight faulting movements, and the low saving is due to the fact that the incipient fractures are not well bound together (rehealed) by later mineral change. They are probably connected with the latest movements of this kind.

Plate 27



CROSS SECTION OF THE CROTON VALLEY AT THE CROSSING OF THE CATSKILL AQUEDUCT.

The tunnel is to pass beneath Croton lake, the present water supply of New York, and carry the Catskill water under pressure to the south side where it will rise to grade again. The rock is all Manhattan schist of both mica and hornblende varieties. The study covers chiefly depth of drift cover, position and extent of crushed rock, probable water circulation, and depth for suitable rock condition.

The commonest secondary mineral now filling these crevices is chlorite, and, although it may completely fill the crevices it has little binding strength. Any new disturbance or strain readily causes separation along the same original lines. But in spite of the fact that the core is broken into small pieces and shows so low percentage of recovery it is quite certain that the rock itself is not badly decayed. An examination of one of the most doubtful looking cores from the lower part of hole no. 1 showed under the microscope little evidence of serious decay. This is believed to mean that underground water circulation is not as abundant as the fractured condition of the rock would lead one to expect. Furthermore, an examination of the cores in greater detail shows beyond question that much of the fracturing is entirely fresh and must have been done by the drill itself. It is certain that the low percentage of recovery is in part due to this cause. The small diameter of the intermediate holes is contributory to the same results. Some allowance must also be made for the difficulty of working a machine from a raft on the lake.

Comparison of the cores shows a decidedly higher percentage of core recovery, and presumably therefore of rock solidity in all of the other three holes — no. 1, no. 5 and no. 15.

Hole no. 2 — core recovered	14.8%
“ no. 1 — “	34.6%
“ no. 15 — “	36.3%
“ no. 5 — “	38.9%

It therefore appears that the last three penetrate rock that is more than twice as good in its capacity to stand drilling disturbance.

A comparison of quality at different depths is believed to be still more encouraging. The upper portions of all holes have poor recovery and comparatively poor looking rock. But in depth there is a marked improvement.

In view of the fact that the tunnel will undoubtedly be located somewhere below the -75-foot level, it is really only this lower section that is of vital importance to the project. A tabulation and comparison of core recovery from these lower portions is given below.

	1 From total depth of hole	2 From depth -75' to bottom
Hole no. 2 —	= 14.8% core recovery	25% core recovery
“ no. 1 —	= 34.6% “	45% “
“ no. 15 —	= 36.3% “	66% “
“ no. 5 —	= 38.9% “	42% “

Under the conditions of work, this is a fair saving and indicates much more substantial rock below the -75' level. There are many pieces 10-12 inches in length and for a 1 inch core this may be considered very good.

It is clear, however, from a detailed inspection of the cores, that there is considerable variation somewhat independent of depth. There are occasional stretches of poorer ground in the midst of comparatively sound rock. This is believed to indicate that the crushed condition is confined chiefly to certain zones, and that these zones dip across the formation and across the holes at an angle. They are probably distributed promiscuously throughout the central portion of the valley, but are certainly more abundant and more strongly marked in the vicinity of hole no. 2 than at any other point tested. The rock profile shows that hole no. 2 has also the lowest bed rock. This is a further support to the general explanation of the valley as given above.

The chief elements of uncertainty remaining after the borings have been completed are:

- 1 The exact extent or widths of the chief crush zones
- 2 Their dip and strike
- 3 The possibility of others not yet touched
- 4 The permeability of the rock for underground water
- 5 The supporting strength of such rock in a tunnel of large dimensions

In spite of the uncertainties enumerated, the conditions are entirely understandable. There is little probability of finding a worse condition than that shown in hole no. 2. The permeability or porosity of these zones is of course unknown. The chief reason for believing that underground circulation is not abnormally heavy is the observation that the joints are well filled with chlorite and that other decay is not at all prominent at the lower levels. Furthermore, the rock is a crystalline type of rather successful resistance to ordinary solution agencies and therefore may be depended upon to hold its own in its present condition indefinitely. But because of the poor binding effect of the chlorite it is to be expected that blocks will fall from the roof of any tunnel where it passes through a crush zone. Timbering will be required for protection in places, but the ground will not cave or run. These zones may be expected throughout a total distance of about 700 feet—i. e. the space between no. 1 and no. 15. The chief belt of such ground probably lies between holes no. 2 and no. 5.

Summary

The lowest bed rock is about sea level.

This pressure tunnel will cut only Manhattan schist.

All rock is good ground for such work, except in certain narrow zones where it is crushed.

The extent of such broken ground is not closely delimited, but occurs at intervals for a distance of 700 feet.

The amount of underground circulation is judged to be moderate at -100 feet.

The tunnel should be located deep enough to take advantage of the improved rock conditions shown at about -100 feet. There seems to be no marked improvement below -100 feet as deep as the drills have gone.

CHAPTER XIII

GEOLOGY OF THE KENSICO DAM SITE

Kensico reservoir at Valhalla, 2 miles north of White Plains, is one of the links in the Bronx river aqueduct. It is to be greatly enlarged and made a very important storage reservoir for the new Catskill system. In line with this plan a new dam is to be built near the old site that will rise 100 feet higher than the present structure.

Extensive investigations¹ have been made to determine the character of rock floor for this massive dam. Sites both above and below the present one have been studied with the question of safety and efficiency and permanence as well as that of economy of construction in view. Involved with this is also the source of suitable stone for its construction.

Geological surroundings

Glacial drift covers the rock floor of this and neighboring valleys to a depth of 10 to 20 feet. No rock is exposed in the valley bottom at the Kensico site, but at the extremities of the proposed dam the rock floor comes to the surface in small outcrops. The material constituting the drift cover is essentially a loose, somewhat porous till passing into modified types, especially gravels and sands immediately south of the ground tested.

The character of bed rock at the two extremities and beyond the limits of the dam is easily seen from the outcrops to be Fordham gneiss on the east and Manhattan schist on the west. Between, although nothing can be seen, Inwood limestone is found by the borings as was to be expected. No other formations occur, although the Yonkers gneiss, an intrusive in the Fordham at a little greater distance figures prominently in studies of material.

The formations are in normal order and are of the usual petrographic character. All dip westward at angles that vary from 45 to 65 degrees and have a general strike a little east of north. It is evident that the whole series represents an eroded limb of a simple fold.

¹These explorations have been in direct charge of Mr Wilson Fitch Smith, division engineer, whose headquarters for the Kensico division is at Valhalla, N. Y. Preparations for construction have already been begun.

The Inwood limestone occupies about 800 feet of the bottom and eastern margin of the valley, lapping well up on the Fordham gneiss. The drill cores from this formation are unusually sound.

The Manhattan schist shows much broken material. There are many crush zones. This condition increases still farther west along the railway near Valhalla station.

The Fordham gneiss appears to be sound where it can be seen at the surface.

Results of exploration. Many borings have been made. They prove the general structure and succession of formations, making the boundaries definite. They increase the evidences of a rather wide prevalence of weak zones—some of them in the gneisses. And they also indicate a more extensive surface decay than was formerly believed to prevail.

The chief problems from the geologic standpoint are connected with the following features:

- 1 Extent of surface disintegration
- 2 Extent and distribution of weak zones
- 3 Depth of decay and perviousness of rock

Surface disintegration. Several borings on ground underlain by Fordham gneiss penetrated material beneath the drift and above bed rock that was interpreted as residuary matter from rock decay. All of this material is of local origin. Later exploration in the form of a deep trench to bed rock has proven that there is an extensive residuary mantle of this sort at the eastern side of the valley below the present dam. In places as much as 30 feet exists. Undoubtedly this material is a remnant of preglacial soil mantle that was in some way protected from removal by the ice. Few places are to be seen in all southeastern New York where there is so much left in place. In most of it the gneissic structure is still preserved, but the decay is so complete that it can be cut and handled like an impure clay.

Weak zones. It has been proven that there are weak zones in the gneisses as well as in the other rock formations. In some places the rock is so poor that no core is recovered for distances of 5 to 10 feet, and in one hole a seam of this kind 20 feet wide appears. In every case, however, the drill passes through the rotten material into the opposite wall—indicating a zone of considerable dip instead of vertical position. This favors the theory that the weaknesses follow the bedding largely and are perhaps due to

CHAPTER XIV

STONE OF THE KENSICO QUARRIES

The following quarries in the immediate vicinity of Kensico reservoir have been studied in the field:

(1) "Smith quarry," which is less than a thousand feet east of the southern end of the present reservoir; (2) "City quarry," which is on the immediate eastern margin of the reservoir on the east side; (3) "Garden quarry," which is a new location about 500 feet from the eastern margin about midway; (4) "Outlet quarry," 1500 feet east of the northern extremity of the present reservoir; (5) "Ferris quarries" 1000 feet and (6) "Dinnan quarry" 3000 feet farther north.

In addition to the field observations a detailed microscopic study was made on specimens of the rock taken from the Garden, Ferris and Dinnan quarries.

The question at issue is the choice of a rock for the facing and finish of the new Kensico dam. In view of the use to be made of the rock, extreme strength is of only secondary importance. But the questions of abundance, distribution, durability, purity, agreeable appearance and working quality are vital.

Types of rocks

All of the quarries occur in the broad belt of Precambrian gneisses that forms the eastern margin of the reservoir extending northward and southward for many miles. The formation as a whole is very complex. But the basis of it is a black and white banded rock chiefly a metamorphosed sediment, known as the Fordham gneiss in southeastern New York. In it are intrusions of igneous rocks of many varieties and most complicated structure — dykes, bosses, veinlets, stringers etc., sometimes in such abundance as to wholly obscure the original type. The most abundant of these are, (*a*) a rather light colored quite acid rock that is essentially a granite in composition, but has a sufficiently foliate structure to be classed as a gneiss and is the same as the "Yonkers gneiss" occurring farther south, and (*b*) a dark rock containing much hornblende and biotite which is in some cases essentially a diorite in composition, but has a marked tendency to schistose structure. The former (*a*) may be called a granite gneiss and the more massive representatives of the latter (*b*) may be classed as a dioritic gneiss. In both cases at

times the blending with the original metamorphosed Fordham gneiss is so intimate that absolutely sharp limits can not be drawn. And this last condition may well be designated as a third case (*c*).

The quarries visited represent all three of these cases. Dinnan, Ferris and Outlet quarries represent essentially the "Yonkers gneiss" type (*a*) of granite gneiss. Garden quarry represents chiefly (*b*) the dioritic type of gneiss. City and Smith quarries represent the last case (*c*), or the mixed and variable type.

Field character

City quarry. In accord with the above differences in type it is found that large quantities of uniform material for such purpose as is proposed can not be obtained from City quarry. The rock there is badly jointed and is variable to a marked degree. It was not thought promising enough to test in detail.

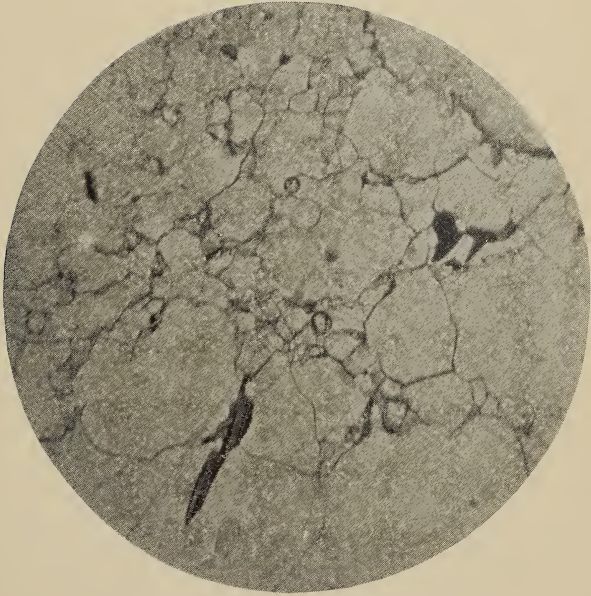
Smith quarry. The conditions of Smith quarry are better but there are similar objections. The amount of uniform material is greater. It would no doubt furnish an abundance of material suitable for use in the construction of the dam interior, but is not at this point as good a source of facing stone as some of the others to be considered.

Outlet quarry. Although this rock is characteristic Yonkers gneiss, it has at this place suffered by weathering a peculiar discoloration to such extent as to make it objectionable, both from the standpoint of appearance and perhaps of durability.

Garden quarry. There is an abundance of stone at the Garden quarry. It is fairly uniform. It is no doubt good enough from every standpoint of durability. It is well located. It can be quarried readily. But it has a very dark color and is undoubtedly less attractive than a light stone for this purpose. There are no objectionable structures, except where the strong schistose character is developed, and these could be avoided so that with a little selection a fairly uniform stone could be secured.

Dinnan quarry. This rock is typical "Yonkers gneiss." There is sufficiently large quantity. It is of good quality. It is situated a little over 2 miles from the proposed dam, but is of easy access. The jointing and other structures do not seem to be objectionable. It will work somewhat more easily than a true granite because of the gneissic structure and it has a good medium light color. The discolorations do not seem to penetrate deep and the rock shows only slight decay.

Plate 28



Photomicrograph of Yonkers gneiss from "Outlet quarry" taken in plain light to show prominence of sutures between the grains indicating the beginning stage of disintegration. Magnified about 30 diameters

Ferris quarries. The "Old Ferris quarry — is "Yonkers gneiss" considerably more weathered than the Dinnan. It is considered less promising than the "New Ferris" quarry which has been explored by the engineers of the Kensico division. The rock of this quarry site is not all of one quality. There are essentially three varietal facies of the Yonkers gneiss type and relationship. One (*a*) is essentially a granite. It has a coarse grain and shows almost no foliate structure. It has a decidedly massive appearance; but it is not of very great extent. This rock is evidently very closely related to the true Yonkers gneiss into which it passes on all sides through an intermediate variety.

This intermediate variety (*b*) has medium size of grain, is only slightly foliated and passes without sharp limitations on the one side into the granite facies and on the other to true normal Yonkers gneiss. It is not so strikingly massive as the granite, but is more so than the gneiss proper. This rock may be called a gneissoid granite to distinguish it from the other.

The true Yonkers (*c*) gneiss surrounds these two special varieties. It is of finer grain than either of the others and is more strongly foliate and is strictly a granite gneiss. Varieties (*a*) and (*b*) occur as sort of a lens within the Yonkers gneiss.

The extent of the granite as now uncovered at the site is believed to represent its limits. The prospect of enlarging the area will not meet with much success. It is essentially a local development connected with the differentiation of the parent magma from which all three varieties were derived. It seems to have been the last of the three to solidify, and it has some of the characteristics of certain pegmatite lenses.

Although this is certainly an attractive rock and one against which there is little ground for objection, it is reasonably certain that a sufficient quantity of this variety can not be obtained here for the whole proposed use. And the prospects are not good for locating another quarry of the same quality.

The gneissoid granite (*b*) is of greater extent, in fact it will be found to encroach on the present area of the granite. It is as good rock and almost as attractive as the granite.

The regular type of Yonkers gneiss such as that represented in the Dinnan quarry can be obtained in almost unlimited quantity, and, with the splendid showing that it makes in further examination, it has come to be considered the best suited to the purposes of dam construction at Kensico.

Petrographic character of the rocks

This line of investigation is confined to four sets of samples.

- No. 1 The granite of the New Ferris quarry
- “ 2 The gneissoid granite of the same quarry
- “ 3 The Yonkers gneiss of Dinnan quarry
- “ 4 The dioritic gneiss of Garden quarry

1 **Granite.** The rock is coarse grained and well interlocked. The chief constituents are orthoclase, quartz and microcline.

There are but small amounts of dark minerals, and there is not much decay.

Both surface material and the drill core were examined. The deeper material shows a little calcite, that may be original, occurring in irregular grains. They do not seem to indicate decay. There is a little kaolin alteration of the feldspars, but not to a serious degree. There are no injurious impurities in the rock such as might cause rapid disintegration or discoloration.

The rock is undoubtedly of good grade as to strength, composition and durability.

2 **Gneissoid granite** (Ferris quarry). The rock is of medium grain, containing quartz, the feldspars and a little mica.

There is very little alteration, and no serious decay or injurious constituents. A small amount of sericite and calcite present are not considered of consequence, and as in the case of the granite, the calcite is believed to be original.

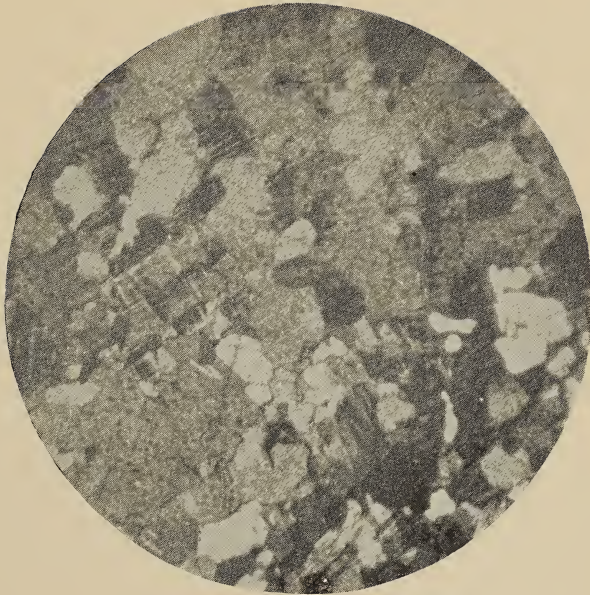
The grains are intimately interlocked and the rock is certainly of good quality and very similar to the granite proper.

3 **Yonkers gneiss** (Dinnan quarry). This rock is fine grained, and is composed of quartz, mica and the feldspars among which microcline is very abundant.

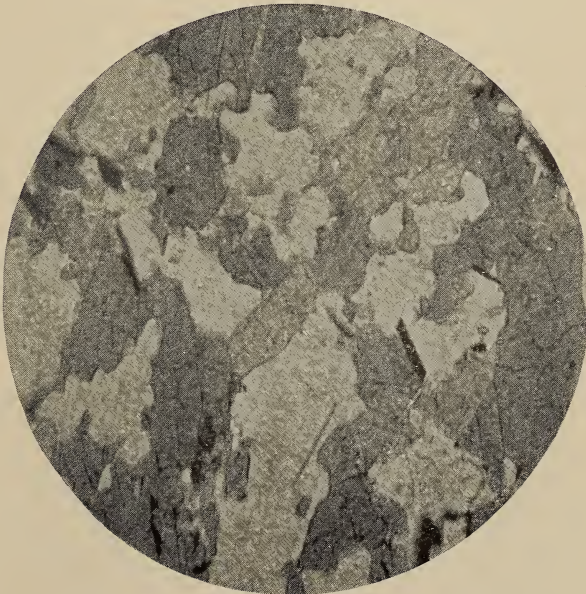
The condition is good,—very little alteration, close structure, but with a little more granular appearance than any of the other types.

It is a good rock and gives good durability tests.

On badly weathered surfaces the Yonkers gneiss breaks up into a granular product like sand long before it decays to earthy matter. This seems to be caused by expansion and contraction of the different constituents under changing weather conditions inducing a weakening of the sutures. Sometimes there is very little decay even along these sutures, but as they open slightly they become the channels for moisture and staining solutions. This makes the boundaries of the grains very well marked in weathered specimens.



Photomicrograph of Yonkers gneiss of the type to be used in the new Kensico dam. Dinnan quarries. Magnified 30 diameters



Photomicrograph of diorite gneiss from "Garden quarry." Magnification 30 diameters. The constituents are hornblende, biotite, feldspars and quartz.

Such incipient disintegration is common in the more even grained or granular varieties.

The accompanying photomicrograph [pl. 28] is taken in plain light and shows the outlines of the grains due to this cause.

4 Dioritic gneiss (Garden quarry). Rock is of medium grain and with a strong tendency to schistose or foliate structure. The dark grains are hornblende and biotite, the light grains are feldspars and quartz.

The rock is fresh, durable and has no injurious constituents. It is good enough for the use in all respects, but has a dark color and is more strongly foliated than any of the others considered.

It is evident from these observations that the rocks considered are all of suitable mineralogic character for the purposes of large dam construction. For very large quantities of material, however, it is probable that neither the coarse granite nor the gneissoid granite could be depended upon for uniform supply. The true regular Yonkers gneiss, however, is very abundant, and can be relied upon for indefinite amounts. The dioritic gneiss is also abundant. The immediate region is not capable of furnishing any better rock than those described above.

Additional tests

Some instructive tests were made by the Board of Water Supply under the direction of Mr J. L. Davis who has charge of the testing laboratories. A few of these applying to the rocks at Kensico are tabulated below.

The tests cover: specific gravity, weight per cubic foot, porosity in per cent, ratio of absorption, per cent water absorbed, ratio of drying 24 and 48 hours, retained water pounds per cubic foot 24 and 48 hours.

In the accompanying tabulation the terms used are subject to the following limitations as to definition:

1 Ratio of absorption, sometimes called porosity, "is the ratio of the weight of water absorbed to the dry weight of the stone."

2 Porosity gives "the actual percentage of the stone which is pore space." "The difference between the dry and saturated weights of the sample is multiplied by the specific gravity of the rock and the product added to the dry weight. This gives the weight the specimen would have provided it contained no pore spaces. The difference between the dry and saturated weights

multiplied by the specific gravity of the rock is then divided by the above computed weight of the poreless specimen. This ratio expressed as a percentage is the actual porosity. Expressed as a formula, the computation is as follows:

$$\frac{(\text{Saturated wt.} - \text{Dry wt.}) \text{ S. G.}}{(\text{Saturated wt.} - \text{Dry wt.}) \text{ S. G.} + \text{Dry weight}} = \text{Porosity.}''$$

3 Ratio of drying. An attempt has been made to determine the comparative and actual rates at which the saturated rocks give up the absorbed water under ordinary atmospheric conditions. "The ratio of drying was computed by dividing the weight of water lost during exposure by total weight absorbed. The weight of retained water was computed." The comparison is most useful in rocks of like petrographic general character.

The other terms need no explanation.

TABULATION OF TESTS

Name	No. of specimen	Ratio of absorption per cent	Porosity per cent	Specific gravity	Weight per cubic foot	Per cent water absorbed	Ratio of drying		Retained water pounds per cubic feet																																																																											
							24 hours	48 hours	24 hours	48 hours																																																																										
Granite, Ferris quarry, core No. 461	1	0.34	0.77	2.66	164.7	0.26	49.45	52.8	.224	.210																																																																										
	2	0.31	0.84	2.65	164.0						Gneissoid granite, Ferris quarry, core No. 468	1	0.32	0.81	2.63	161.0	0.28	67.48	69.88	.146	.145	2	0.25	0.71	2.65	162.8	Yonkers gneiss, Dinnan quarry	1	0.30	0.87	2.64	163.3	0.30	88.16	88.16	.057	.057	2	0.39	1.01	2.64	161.0	Dioritic gneiss, Garden quarry, core No. 459	1	0.42	0.68	2.83	175.4	0.21	62.5	62.5	.137	.137	2	0.24	0.68	2.86	174.8	Gneissoid granite, Ferris quarry, surface	1	0.37	0.96	2.63	162.5	1.08	86.7	88.2	.252	.215	2	0.98	2.50	2.62	159.4	Granite, Ferris quarry, surface	1	0.44	1.12	2.63	162.3	0.40	70.0	74.0	.207
Gneissoid granite, Ferris quarry, core No. 468	1	0.32	0.81	2.63	161.0	0.28	67.48	69.88	.146	.145																																																																										
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Yonkers gneiss, Dinnan quarry	1	0.30	0.87	2.64	163.3	0.30	88.16	88.16	.057	.057																																																																										
	2	0.39	1.01	2.64	161.0						Dioritic gneiss, Garden quarry, core No. 459	1	0.42	0.68	2.83	175.4	0.21	62.5	62.5	.137	.137	2	0.24	0.68	2.86	174.8	Gneissoid granite, Ferris quarry, surface	1	0.37	0.96	2.63	162.5	1.08	86.7	88.2	.252	.215	2	0.98	2.50	2.62	159.4	Granite, Ferris quarry, surface	1	0.44	1.12	2.63	162.3	0.40	70.0	74.0	.207	.180	2	0.19	0.50	2.71	167.3																										
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Mr Davis concludes from a careful analysis and interpretation of these tests that the Yonkers gneiss is of superior durability.

CHAPTER XV

THE BRYN MAWR SIPHON

Geologic conditions as shown by exploration for a proposed pressure tunnel

Bryn Mawr is a railway station 2 miles northeast of Yonkers. The general features of the vicinity, its topography, succession of formations and the boundaries are shown on the accompanying sketch map which is largely copied from United States Geological Survey Folio No. 83. The Southern aqueduct follows southward along a Manhattan schist ridge until, at a point about a mile northeast of Bryn Mawr, a cross depression of so great width and depth is reached that some special means of crossing has to be devised. Near Bryn Mawr station a gneiss ridge rises and continues southward. The proposed line follows this ridge.

Explorations have been made as usual by drilling to determine if possible whether or not a bed rock pressure tunnel is practicable.

The following questions may be made to cover most of the practical issues of the study:

- 1 What formations would the tunnel cut?
- 2 Which of these would show most questionable ground?
- 3 What portion of the line is regarded as most critical — whose development would show whether or not a tunnel is practicable?
- 4 What special conditions are shown by drill borings?
- 5 What interpretation is to be placed on the peculiar results from hole no. 4 where there has been unusually great difficulty in drilling?
- 6 What experiences in similar ground have a direct bearing on this case?

Formations

The formations that would be encountered in the Bryn Mawr siphon are:

- 1 Manhattan schist (top), the usual micaceous type, also called Hudson schist in United States Geological Survey Folio 83.
- 2 Inwood limestone (middle), the usual coarsely crystalline dolomitic and micaceous type, also called "Stockbridge dolomite" in the Folio, same as "Tuckahoe marble," same as "Sing Sing marble," same as limestone at Kensico dam and also at Croton dam.

3 Fordham gneiss (bottom), the usual black and white thinly banded type, a much folded and strongly metamorphosed rock, the oldest of all.

4 Yonkers gneiss, the usual type, gneissoid biotite granite very uniform and granular. This formation is an igneous intrusive that cuts up through the Fordham gneiss and is therefore younger. Whether it is also younger than the limestone and schist is not clear.

5 Quartz veins and lenslike segregations of quartz, also pegmatitic streaks, are occasional occurrences in all of the formations. They are most abundant in the schist, but are seen also in the Fordham gneiss. A similar development was encountered in the limestone in hole no. 40.

6 Glacial drift, chiefly modified drift, partially stratified sand and gravel, reaching more than 125 feet in depth, covers portions of all formations.

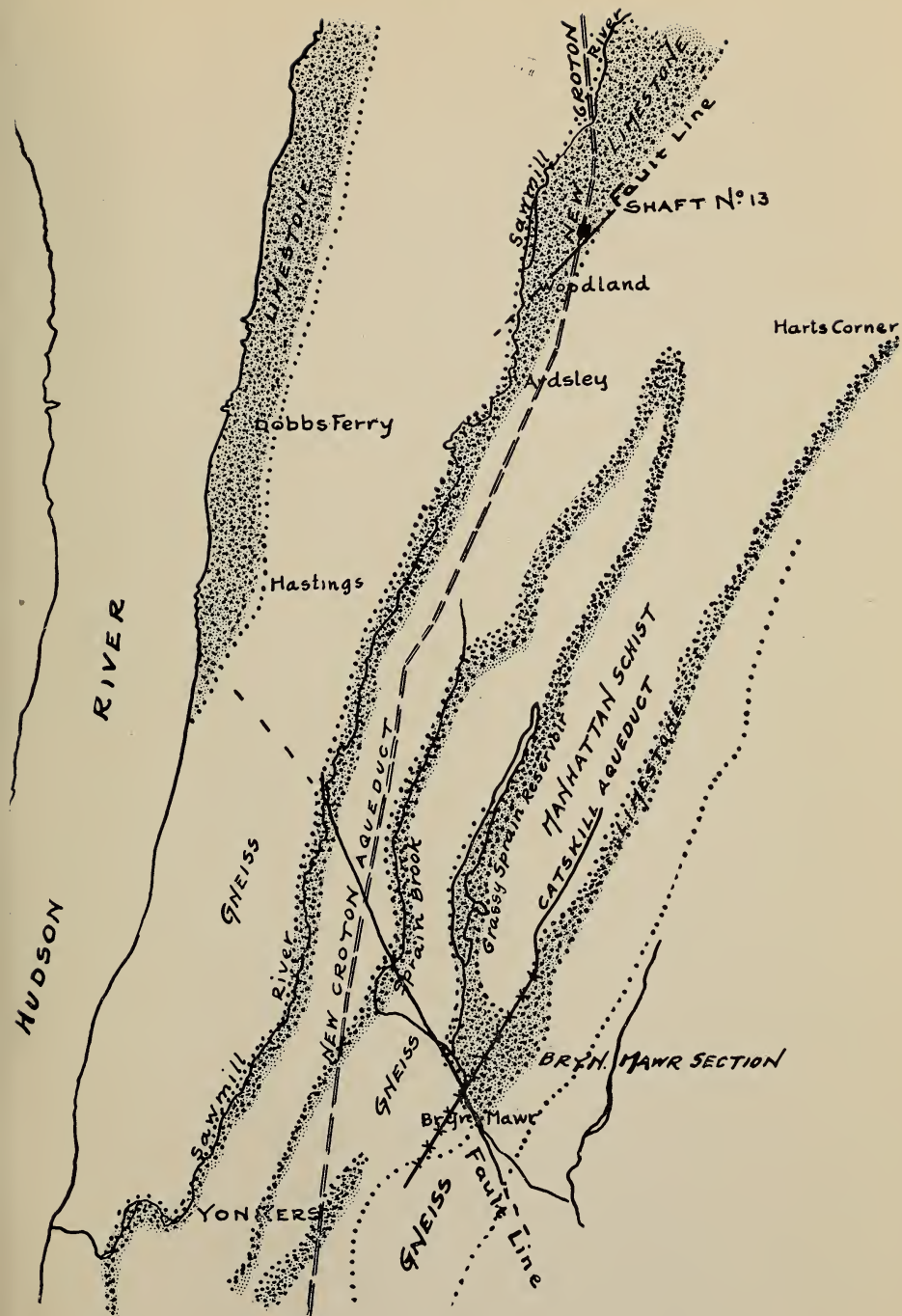
This last formation (no. 6) is the only one that may be wholly avoided in the tunnel proper. The chief interest lies in its hindrance to exploration and its possible usefulness as a source of sand and gravel supply.

Weakest formation. The Inwood limestone is the most questionable ground. This is believed to be so chiefly because of the greater solubility of the rock, its granular and micaceous character, and the probability that a line of displacement accompanied by some fracturing crosses the siphon line in this formation. If a very excessive amount of shattering occurs in this zone it may have induced a condition of disintegration to such depth as to endanger the tunnel.

There are no surface indications of a serious condition at depth for any of the other formations.

Critical zone

The critical zone is probably not far from the contact between gneiss and limestone. There are two reasons for this opinion. The first is related to the nature of the folding. The formations are squeezed into a close syncline pitching northward. In cross section the strata at any point around the head of this trough dip inward, and, because of the more resistant Fordham gneiss forming the floor of the trough, the drainage and seepage and consequent tendency to decay might be expected to follow along its upper contact.



Location map showing by the dotted belts the distribution of Inwood limestone in the Hastings-Yonkers district and the position of the Bryn Mawr tunnel section as well as shaft 13 on the New Croton aqueduct with their relations to the limestone belts. Manhattan schist and Fordham gneiss occupy the rest of the area.

The second reason is related to the probable later faulting movements. It is evident from the map [Folio 83] that the formations in the vicinity of Bryn Mawr are bulged up. One would expect the trough which contains the schist and limestone of Grassy Sprain valley to continue uninterrupted southwestward and join with Tibbit brook valley. But a cross fold has bulged the formations up so much that for a distance of a mile erosion has removed all of the formations except the gneiss. Bryn Mawr station is about central on this bulge. Evidence of such a movement is readily seen on the gneiss along the northerly margin where it slopes down toward the limestone. The movement had developed a little shearing and has tilted the minor folds downward toward the north at angles varying from 30° to 80° from the horizontal. This angle becomes somewhat more accentuated as the limestone is approached, and it is believed that it may pass a short distance into the limestone border. There is, however, no great amount of crushing evident in the gneiss and this may hold also in the limestone.

The fact that Sprain brook crosses the formations along this northerly margin and flows for 2 miles in a southeasterly direction may indicate a still later movement, probably faulting. There is no surface evidence of it except the abnormal course of the creek. But, if there is such a fault, it also crosses the siphon line in the same zone, i. e. in the vicinity of the limestone-gneiss contact, not far from the location of the present course of the brook.

Therefore it seems reasonable to conclude that the critical zone is near the contact, probably on the limestone side, and in the vicinity of the present course of Sprain brook. It is also probably cut deepest here by erosion. If this zone is in good enough condition to stand tunneling the rest of the line ought to be.

Conditions indicated by borings

All rock formations stand very steep. They vary from 80° to 90° . This means that very few beds can be explored by one hole, and that any weakness or crevice is likely to make a showing in excess of its true proportions.

The cores show considerable crushing. Some of the fractures are not healed, although weathering from circulation is not present on all of them. The micaceous layers are most affected by circulation. Some beds of this variety are considerably weakened even at depths of over 200 feet. Occasional seams have been encountered that give no core at all for several (even 20 or 30) feet. But the

greater proportion of the recovered pieces are comparatively solid even where the total percentage of saving is very low. It is evident that some of the core, a considerable percentage, has been ground to pieces in the process of boring. This is especially noticeable at hole no. 40.

Hole no. 40. Much trouble has been met in this hole. A careful analysis of the record and core and the behavior of the drill is interpreted as follows:

1 Partially assorted drift, chiefly sand and gravel was penetrated for 125 feet.

2 Limestone bed rock of fairly sound quality was struck at about 125 feet (about el. -40).

3 The casing that was put down to shut out the sand failed to reach solid rock, and this permitted a continual supply of pebbles and sand to run into the hole and obstruct the work with each pull up. The presence of these pebbles was also instrumental in grinding the core to pieces, and this accounts chiefly for the low saving.

4 After this opening was plugged up with cement, the drilling was continued successfully until a somewhat broken quartz vein was encountered and this has been followed for about 35 feet. Its broken condition afforded another opportunity for fragments to fall into the hole, and on top of the drill, bringing the work for a second time to a standstill. It is certain also that the drift pebbles still fall in. As the formation stands vertical here it is not surprising that any feature should show an apparent extent quite out of proportion to the real value. The quartz vein is probably of no great breadth. Small seams containing mud may also be followed 15 or 20 feet and still be of no great significance in the formation as a whole. The rock fragments (core) recovered in this hole are fairly sound.

5 In spite of the many delays and difficulties of this hole, it is apparent that the general rock formation is not responsible for it all. The failure to reach solid rock contact with the casing has been the cause of part of it. Later the penetration of a rather rare quartz vein, a thing that would not often be found in the limestone, has added to the trouble. Both of these causes are so rare that they may almost be given the value of accidents.

But the last 100 feet or more of the hole, from depth 225 feet to 335 feet, shows an unusually questionable condition. Only a few rock fragments are saved and they include limestone and quartz vein matter. The rest is wholly disintegration sand of rather complex composition but carrying very much mica. This is all wash

material except one sample, which is a "dry sample" and is still more strongly micaceous.

Borings nos. 40, 45 and 46 are all within the zone that was considered, from surface indications, to be likely to carry the deepest gorge and to show the weakest rock. Because of the heavy drift cover (more than a hundred feet) it is manifestly impossible to locate the weakest zone more closely or judge of its exact condition except by borings.

Hole no. 42 at station 634 + 28, penetrates 82.4 feet of drift and reaches bed rock at about elevation 21 feet A. T. The rock is good, substantial, coarsely crystalline limestone. It shows as sound condition as can be expected in this formation even under the most favorable situations.

Hole no. 46 at station 644 + 77.4 is just south of the brook. It penetrates 72 feet of drift and reaches bed rock at elevation 14 feet A.T. The rock is Fordham gneiss of typical sort and in perfectly good condition. There is no question about the soundness of the rock from this point southward.

Hole no. 45 at station 643 + 52.5, 125 feet north of hole no. 46 penetrates drift for about 150 feet (possibly a few feet less, 145 feet). This drift cover is interpreted as mostly sand (modified drift) to 115 feet and a boulder bed from 115 to 143 feet. After the true ledge is reached it is sound and shows no unusual or questionable conditions. It is Fordham gneiss.

Interpretation

1 **Weak zone.** There is little doubt that this last 100 feet of hole no. 40 is in the decayed weak zone that was expected to develop in the vicinity of the contact between the gneiss and the limestone. It would be expected to pitch northward along the floor of gneiss and extend beneath the southerly extremity of limestone at this point [*see* fig. 36].

2 **Contact.** Hole no. 40 cuts limestone, hole no. 45 cuts only gneiss, therefore the formational contact lies somewhere in this 177-foot space.

3 **Position of old channel.** Bed rock surface is lowest at hole no. 45. But since the rock itself is sound gneiss, it is not believed to represent the lowest possible point. This is still more certain because of the fact that the pitch is northward so that this becomes a dip slope on which the preglacial stream could glide against the edges of the limestone beds [*see* diagram], and because the condi-

tion of the rock a little farther north (at hole no. 40) shows that these limestone beds are actually much weaker than the gneiss. Therefore the deepest portion of the buried channel is to be expected between holes no. 40 and no. 45, and probably nearest to hole no. 40.

4 Depth of old channel. How deep the buried channel may be can not be accurately estimated. But if the same dip slope as is shown by the rock surface from hole no. 46 to no. 45 prevails northward toward hole no. 40, a depth somewhat below -100 feet may reasonably be expected. In the absence of data bearing upon the depth of other portions of this ancient channel or of the lower Bronx river with which it must have been connected, it is impossible to estimate more closely.

5 Interpretation of hole no. 40. There is so little rock actually saved from the more than 200 feet of possible core on this hole that its real character is very obscure.

There are three possible explanations for the condition found in the last 100 feet.

a The drill may have followed a large mud seam.

b The material may be only residuary rotten limestone still wholly above the gneiss.

c The actual contact may have been penetrated and a part of this rotten material may be decayed gneiss within a crush zone.

The difficulty in drawing absolute conclusions is increased by the fact that matter falling in from above has been a continued source of trouble and is more or less mixed with the rock material of lower points. Therefore, the fact that the sand taken from the lowest points, 335 feet, is silicious instead of calcareous, may not prove satisfactorily that the rock at that point is wholly silicious.

It is worth noting, however, that the harder rock in the upper portion of the hole was in places much crushed and that mud seams were encountered before reaching this last 100 feet.

It is also worth noting that the same dip slope of rock surface as prevails between holes no. 46 and no. 45 if continued northward to hole no. 40, would cut that hole a considerable distance (75 feet) above its bottom.

In view of all the conditions, therefore, it is judged that there is a crush zone here, that hole no. 40 penetrates it, that it is badly decayed, that the plane of the crush zone dips steeply northward and cuts both limestone and gneiss, that a tunnel at about -300 feet would cut this zone south of station 640 and north of station 642, and that all other portions of the line are in comparatively satisfac-

tory condition. This zone for a hundred feet is likely to be wet, weak, and would require extra precautions and additional expense in construction.

6 Evidence of faulting. Whichever interpretation of hole no. 40 is taken is in support of some displacement in the nature of faulting between holes no. 40 and no. 45. If the gneiss rock floor is not reached in hole no. 40, then the greater northward slope of it from hole no. 45 to no. 40 than is shown from no. 46 to no. 45 indicates a downward movement. If on the other hand, the identity of the formation in the lower part of hole no. 40 be considered undetermined, and its condition attributed to decay in a crush zone, the presence of the crush zone itself indicates movement of a fault nature.

Conclusions as to character of the crossing

In considering the geological conditions as a factor in the problem of practicability of a tunnel, it is necessary to note the following points:

1 In view of the fact that the deepest point in the ancient channel is not yet found, and that it will probably go below -100 feet, it would be necessary to figure on a tunnel grade down well toward -300 feet.

2 It would be necessary to figure on a wet and weak zone of at least 100 feet along the tunnel and a more expensive construction at that point.

3 The ground at such depth south of station 642 is unusually sound. The ground north of station 636 may be counted good. The ground between 636 and 640 may be considered fair, and the ground from 640 to 642+, troublesome, containing the chief elements of uncertainty.

Fig. 36, which is a geologic section along the line at this point, shows the distribution of these features drawn to scale.

CHAPTER XVI

A STUDY OF SHAFT 13 AND VICINITY ON THE NEW CROTON AQUEDUCT

[See outline location map, pl. 30]

There has been reference made occasionally in connection with the Bryn Mawr explorations, as well as others, to the remarkable piece of bad ground encountered in 1885 on the New Croton aqueduct near Woodlawn in the Saw Mill valley. This experience has been the source of much misgiving. Because of its evident importance and close relationship to conditions that may exist in the same formation at points on the Catskill line, an examination of this ground was made for the purpose of comparison. The meaning of that case and its bearing on the Bryn Mawr questions are given below:

Engineer's records

This ground and its remarkable behavior is described by Mr J. P. Carson in the Transactions of the American Institute of Mining Engineers, September 1890, pages 705-16 and 732-52.

A description is also given in Wegman's *Water Supply of the City of New York*, 1658 to 1895, on page 152.

From Mr Wegman's report is taken the following:

The south heading was started from this shaft on June 1, 1885. It advanced at the rate of about 80 feet per month for 392 feet through good limestone rock (dolomite), which then became softer. On December 9, 1885, when the heading had reached a point 407 feet from the shaft a fissure was encountered from which about 100 cubic yards of decomposed limestone clay, sand and dirty water poured into the tunnel, partly filling it for a distance of 125 feet. After three days delay, when only clear water was flowing into the tunnel, the fissure was plugged with straw. The heading was advanced 20 feet further until on December 22, 1885, an outpour three times greater than the first occurred, covering everything in the heading out of sight * * * borings were made on the surface with a diamond drill to determine the extent of the soft ground in front of the tunnel. It was found to lie in a pocket in the rock,

which had a length of 110 feet on the axis of the tunnel and extended for a short distance below the invert of the conduit. The soft material, consisting of sand, gravel, clay and decomposed rock had a depth of about 160 feet from the surface to the top of the tunnel. It exerted such a pressure against the timber bulkhead that the 24-inch oak logs used as "rakers" (braces) became crushed in 24 hours and had to be continually renewed.

The chief points of present interest are that the tunnel, at a depth of about 160 feet from the surface, and after passing through several hundred feet (407 feet) of good dolomite, came into rotten rock and soft ground 110 feet across on the line. It was so soft that it ran into the tunnel in great quantities and exerted such pressure as to make progress in it a very troublesome and costly matter, taking "60 weeks to advance the tunnel 85 feet" and costing "\$539 per foot." The material caved in so freely as to form a pit on the surface.

Statement of geologic conditions

It is not possible to interpret the conditions at this locality as fully as one would wish because of the vagueness of some of the statements, but the following facts and explanation are essentially correct:

1 The rock is the Inwood limestone, the same kind and same general conditions as all of the limestone belts that occur in the region of the Southern aqueduct.

2 The soft ground penetrated at the point in question — 407 feet south of shaft 13 — called in the Carson report and others "a fissure" or "pocket," etc., is in reality a fault crush zone. The fault plane probably dips steeply southeast and strikes n. 50° e. cutting the tunnel line at an angle of something like 20°.

3 The point is well up on the side of the valley more than a hundred feet above Saw Mill river, and the strike of the fault zone in its southwesterly extension cuts into the lower portion of the valley, so that underground circulation would be encouraged along the zone in this direction.

4 The limestone outcrops very near by on the west side of the line and the Manhattan schist occurs near by on the east. The attitude of the beds is such as to indicate a fault of the thrust type. The accompanying figure illustrates this relationship in a cross section at right angles to the axis of the tunnel [*see* fig. 37].

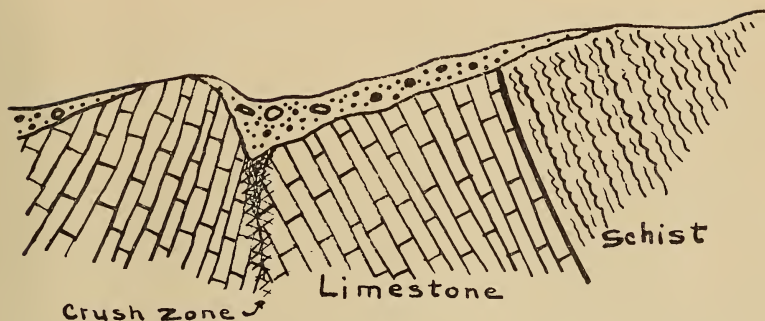


Fig. 37 Sketch of the geologic structure at shaft 13 on the New Croton aqueduct. Interpreted from field observations

5 It would appear probable that this zone was penetrated at the worst possible level, i. e. near enough to its wholly decayed upper part to furnish no resistance at all to the overlying sand and gravel, and not deep enough to reach the more substantial (although probably crushed) rock that may reasonably be expected to prevail at no very much greater depth.

The chief point is that the weak spot has a reason and is not an accidental thing that might be expected just anywhere. But it must be admitted, in spite of this fact, that a casual examination of the locality would not make one suspicious of its existence, and it is surprising that the spot could have caused so much trouble.

From the above it will be seen that in several respects the Bryn Mawr case is somewhat similar to this. They both indicate faulting; they are in the same type of rock; they both show or indicate caving tendencies.

On the other hand, there are certain elements of difference some of which are capable of very materially modifying any conclusion that might be based upon the simple facts of likeness. For example — it should be expected (1) that the fault movement at shaft 13 would be the greater because of lying in the more prominent lines of such displacement of the region, (2) being a thrust movement, the crush effect is probably more prominent at shaft 13 than at Bryn Mawr, (3) occurring at greater elevation above probable circulation outlet, the opportunity at shaft 13 for extensive and rather deep decay is the greater, (4) being cut so near the surface (160 feet), its condition there is not necessarily a reliable guide to the seriousness of decay at a greater depth.

Comparison of Bryn Mawr and shaft 13

The following statements embody an opinion on the points raised or suggested in connection with a reference to the New Croton difficulties at shaft 13. The items are therefore treated by comparison or contrast so far as possible:

1 Type of rock. The rock explored at the Bryn Mawr siphon is the same formation as that in the Saw Mill valley cut by the New Croton aqueduct, i. e. the Inwood limestone — sometimes called "Stockbridge dolomite." It is the same also as the other large limestone belts in Westchester county. There are occasional small strips of limestone of another type, but its behavior could not be very different.

2 Soft material. "Is any material of this sort" (like that in the New Croton tunnel near shaft 13) "likely to be encountered either in the crushed zone at boring 40 or elsewhere in the limestone belt?"

It is sure to be encountered, especially near hole 40, if that zone is cut shallow. The behavior of the lower portion of this hole is very similar to the described case near shaft 13. The only probability of avoiding it lies in placing the tunnel deep enough to cut more substantial rock. The single hole upon which all this argument is based can scarcely be considered a thorough enough exploration to build up a quantitative statement as to depth or width.

There is no evidence, either on surface or in the exploration holes, of any other such zone on this line.

3 Depth and extent. Under the circumstances, the increased depth makes it less probable that so much ground of like behavior would be found. Again, it is not likely that precisely the same conditions would so effectually halt operations or be considered so nearly insurmountable at this time. One of the many serious objections is that the tunnel would have little strength or resistance to a bursting pressure. It must be admitted that if caving ground were penetrated it would prove very difficult to handle with the gravel cover at the depths now considered, i. e. 300 feet or more below the surface.

4 Water. "What are the probabilities in regard to the quantity of water to be met in the crushed zone near boring 40? Can any limit be set which it would be extremely improbable that the inflow would exceed, on account of the topography of the country and the nature of the overlying materials?"

There is likely to be much water. Nearly all of the overlying

drift is sand and gravel that is probably saturated and in such condition as to permit easy flow to any lower outlet. It may readily carry 8-10 quarts of water to the cubic foot or about 2 gallons. The area covered by such deposits is about 2500 feet long on the southerly base along the creek and at this margin is approximately 150 feet deep. The northerly margin is variable and reduces in places to 0 feet in thickness. It may, however, really represent 500,000,000 cubic feet of this gravelly material holding 1,000,000,000 gallons of water as a nearly permanent supply.

This overlying material is necessarily a menace of no mean proportions. Every crevice or crush zone remaining unhealed will have water and plenty of it, the inflow being limited only by the size of the cracks and their abundance until the reservoir should be drained. There is no hardpan bottom to act as a dam.

Outside additions to this permanent supply are confined to that received from rain and the stream. The rainfall on the area and immediately available as addition to the underground supply in the lower sands, together with the stream flow, which would probably sink into the sands, if an attempt to drain the underground supply were made, may be expected to furnish additional water at a possible rate of 2500 gallons per minute. How much of all this is available at tunnel level depends wholly upon the openness of structure in the rock. There is nothing else to materially control the permanent and additional supply.

There is evidence in hole 40 of considerable crushing. That means capacity for water circulation, but how much no one can tell. There is also much rotten rock in the same hole. This means that circulation has been easy and effective, but how much now no one can tell. The single hole (no. 40) in the absence of any other corroborative data is not sufficient to base more elaborate or precise quantitative estimates upon.

5 Solubility. What is "the nature of the limestone with reference to its resistance to solution?"

This limestone is, as all limestones are, more easily attacked by circulating water than most other rock types [*see* Rondout Valley]. The Inwood limestone such as occurs at Bryn Mawr is crystalline, often contains much mica and then is inclined to be foliated in structure, and it prevailingly stands steeply inclined. Because of these features in which it differs from the Rondout Valley limestones, it is likely to be more generally affected by decay along the zones permitting circulation than any of the Rondout Valley types.

The Rondout Valley limestones are affected along joint planes, but the effect is almost wholly confined to a simple enlargement of these crevices. In the Inwood an additional effect is the weakening of the sutures or bond between the individual granules resulting in a tendency to weaken the whole mass as far as there is much penetration of seeping water. It would have less tendency to produce openings or caves, but greater tendency to produce a rock that would crumble in the hand or that would gradually assume the condition of a lime sand or a micaceous mud.

As to the effect of water from the aqueduct on fresh portions of this rock, it is certain that the rock would be attacked wherever exposed to direct action. Its method of attack is by solution, and the rate of attack may safely be reckoned as not materially different from that assumed or being established by experiment and experience on the Rondout Valley types.

In the final consideration of the difficulties at Bryn Mawr the engineers have decided to abandon the tunnel plan. It is probable therefore that no additional explorations of direct bearing on the problems of this ground will be made.

CHAPTER XVII

GEOLOGICAL CONDITIONS AFFECTING THE LOCATION OF DELIVERY CONDUITS IN NEW YORK CITY

Hill View reservoir is the terminus of the Southern aqueduct. The Catskill water is to be delivered at this point, just north of the New York city line on the Yonkers side, at an elevation of 295 feet. From this reservoir the water is to be distributed by an independent system of conduits to the principal centers of consumption in lower Manhattan and Brooklyn.

It is believed that distribution can be most economically made and the system be most permanently established by constructing the main trunk distributaries as tunnels in solid bed rock at considerable depth below all surface disturbances.

Preliminary investigations have been carried on by Headquarters department, Mr Alfred D. Flinn, department engineer, beginning in 1908. As the active work of exploration was entered upon Mr William W. Brush, department engineer, was assigned to this special division of the department's work and most of the preliminary exploration borings were planned and finished under his immediate supervision. With the resignation of Mr Brush to take the post of deputy chief engineer in the Department of Water Supply, Gas and Electricity, Mr Walter E. Spear, department engineer, was secured to continue the difficult work of finishing explorations and preparing for construction.

Studies of conditions affecting such a system and explorations designed to test the ground in line with these studies¹ have been made. The work thus far done in an exploratory way has been confined to one main distributary.

Section A. Preliminary geological study

As a preliminary step toward the systematic study of local conditions affecting possible conduits, trial lines were laid out on the

¹ Few engineering enterprises, probably, have been planned with so careful regard for all known geologic conditions. The geologist and the engineer worked alternately on the same problems until, in the opinion of both, the best possible line was selected. It is the writer's belief that so systematic a method has seldom if ever been carried out in engineering work of this kind. On this account, and in part to illustrate some of the preliminary stages in such work, many of the original facts and arguments and suggestions are given without change in the following discussion.

city map from Hill View reservoir to Brooklyn by three different routes. So far as the topography and city development and other engineering considerations could be forseen either route could be used. Studies of all kinds were expected to indicate which would be the most favorable and whether or not it might be advisable to shift even the best one to still more favorable ground. These are shown on the accompanying map which also covers the local geology of the immediate vicinity of the lines [*see* pl. 32].

General questions

When the problem of the practicability of a rock tunnel for distribution conduits was first studied, several general questions were raised which indicate the lines of investigation followed.

1 What is the character of the rock along the projected conduit lines shown at the depths required for such tunnels?

2 Will the rock at moderate depths be such as to permit successful and economical construction of tunnels to be used under the hydraulic pressure due to Hill View reservoir?

3 Does the character of rock in the vicinity of the lines vary sufficiently to materially affect the cost of a tunnel if the lines be shifted approximately 1000 feet either way from those shown on the original map as trial lines?

4 Are the suggested locations of conduit lines adapted from a geological viewpoint to the construction of pressure tunnel conduits, and, if not, what changes in these lines would be advisable?

5 Is the thickness of rock covering sufficient at all points to obviate trouble from open seams and disturbed surface rock?

6 What borings and other field investigations should be undertaken to determine the practicability of construction of pressure tunnels along the lines suggested?

In line with this series of questions a thorough geological investigation was begun, the chief conclusions of which are given below.

Geological formations

There are six local formations of sufficient permanence and individuality of character and of sufficient areal importance to be treated as units in this study. These are described in some detail in part I, but for convenience are briefly listed as follows:

1 Glacial and postglacial deposits of boulders, clay and sand, with silt beneath the rivers.



A relief map of New York city and environs. Reproduced from a model by Howell.

2 Manhattan schist, the most abundant formation, chiefly mica schist with very subordinate hornblende schists, and usually with abundant pegmatite lenses and veins.

3 The Inwood limestone, a white, dolomitic marble when fresh, which shades into impure, micaceous varieties.

4 The Fordham gneiss, varying from a thinly schistose or quartzose rock to a strongly banded or a very massive and much contorted gneiss. The oldest formation of the district.

5 The Yonkers gneiss, an original intrusive granite, now squeezed into a gneiss. Younger than the original Fordham.

6 The Ravenswood grano-diorite or as it might be called in engineering practice, granite; an original, intrusive rock now somewhat gneissoid from pressure. Younger than the original Fordham.

The Manhattan schist, the Inwood limestone and the Fordham gneiss are cut by veins or dikes of coarsely crystalline granite, technically called pegmatite. They are of irregular distribution and do not affect the tunneling operations one way or another.

All the formations older than the glacial drift have been compressed into a series of northeast and southwest folds, and all have as a rule a steep or almost vertical dip. The axes of the folds are not horizontal, but usually pitch downward to the south at low angles. Erosion has developed a series of ridges trending northeast and southwest. The limestone being a softer and more easily eroded rock, almost always underlies the valleys or flats and the river channels. It is certain also that there is some faulting.

Rock at depth

The distribution of geological formations along the proposed lines has been shown on the accompanying map [pl. 32]. In general the kind of rock at tunnel depth will be the same as at the surface as indicated on the map for each point. Such error as there is, arises from two causes: (*a*) Uncertainty as to the exact location of some of the contact lines between two formations (usually due to drift cover), and (*b*) dip and pitch of the strata.

In the first case (*a*) where the drift is particularly heavy, it is sometimes impossible to fix a contact line accurately from surface features alone.

In the second case (*b*) it must be appreciated that nearly all of the formations dip eastward at a very steep angle, so that a formation would usually be found to extend a little further east at depth than at the surface. And also all formations pitch southward, so

that they would be found to extend considerably farther south at depth than their surface outcrops. This angle of pitch is from 10° to 30° .

In nearly all these cases, however, the obscurity of the actual surface boundaries is as great a source of uncertainty as the effect of dip and pitch, so that the boundaries as mapped may be considered sufficiently accurate for this comparative study of the lines.

It is worth noting that the rock at the proposed depths of tunnels would be, as a rule, more substantial than at the surface. But there are several places on all of the lines where the exact condition is unknown at the surface as well as at depth. The chief points of this character will be noted in a later paragraph.

Comparison of lines¹

A comparison of the three lines submitted as the basis of examination — (a) the westerly one, (b) the central one, (c) the easterly one [*see* accompanying map, pl. 32], as to rock formations likely to be cut by them, furnishes the following figures:

Line A. Going southward from Hill View reservoir

Feet	
6 200	Yonkers gneiss — good rock
1 400	Fordham gneiss
1 400	Probably largely Inwood limestone with one weak zone (at Van Cortlandt lake)
5 600	Fordham gneiss — good rock
2 400	Near contact with limestone, probably in gneiss
1 600	Crossing Harlem river — Inwood limestone
4 000	Inwood limestone — probably fairly good rock
800	Inwood limestone — probably containing bad zone to Speedway
16 400	Manhattan schist (to 135th st.)
2 000	Along contact between schist and limestone
4 200	Inwood limestone with one weak zone (to s. end of Morningside Park)

¹The statements of quality and extent of certain formations and zones are capable of some modification as exploratory work progresses. Some of these are noted in later sections of this report under special headings, such as The Lower East Side, and The East River-Brooklyn section. For the present purpose, as showing the development of the geologic basis of the project it seems preferable to leave the accompanying comparisons in their original form as presented to the board.

- 12 800 Manhattan schist probably good quality (to s. end of Central Park)
- 21 000 From Central Park to East river—no outcrops—mostly Manhattan schists at tunnel depth. Condition largely conjectural¹—probably mostly good rock with occasional weak zones
- 6 000 Manhattan island to City Hall, Brooklyn. Containing an unknown¹ zone in the East river and unknown quality of rock in Brooklyn.

Summary of Line A

Feet	
6 200	Yonkers gneiss
7 000	Fordham gneiss
2 400	Contact (probably in gneiss)
12 000	Inwood limestone
2 000	Contact (probably in limestone)
29 200	Manhattan schist (good)
21 000	Estimated Manhattan schist (fair)
6 000	Almost unknown
85 800	total

Line B. Going southward from Hill View reservoir

Feet	
8 000	Yonkers gneiss—good quality
13 000	Fordham gneiss—good quality
6 800	Inwood limestone, probably mostly in fair condition, except at two points (to Cromwell av.)
6 600	Inwood limestone, unknown condition, but probably largely poor (to Harlem river)
600	Inwood limestone—unknown condition (Harlem river)
4 600	Inwood limestone—unknown condition—probably fair (to Mt Morris Park)
800	Manhattan schist, good
800	Probably Manhattan schist—unknown
2 800	Inwood limestone—unknown condition—probably at least one bad zone (to 106th st.)
12 000	Manhattan schist along Central Park—good

¹ Explorations since conducted by the Board of Water Supply have proven the quality and character of the rock floor at these places. For the revised statement on these sections see the special discussions.

Feet	
8 600	To Broadway — Manhattan schist (little known except from tunnels already made)
14 000	To East river, probably Manhattan schist (same as line A)
6 000	Manhattan island to City Hall, Brooklyn — uncertain condition (same as on line A)

SUMMARY OF LINE B

Feet	
8 000	Yonkers gneiss — good quality
13 000	Fordham gneiss — good quality
21 400	Inwood limestone — variable quality
12 800	Manhattan schist — good quality
23 400	Estimated Manhattan schist — fair
6 000	Almost unknown
<hr/>	
84 600	total

Line C. Going south from Hill View reservoir

Feet	
6 000	Yonkers gneiss — good rock
17 400	To Webster av.— Fordham gneiss — good rock
5 000	Along contact between limestone and gneiss
9 800	To 138th st.— Inwood limestone with probably two bad zones
1 800	To Bronx kills — along contact between limestone and gneiss — uncertain quality
600	Across Bronx kills — mostly in limestone containing a fault zone — probably bad ground
6 400	Crossing Randall's and Ward's islands and Little Hell Gate. Nearly all is Manhattan schist of good quality
1 000	Crossing Hell Gate — Inwood limestone
1 200	Crossing Hell Gate — Fordham gneiss of good quality
1 800	Astoria point — probably Fordham gneiss of good quality
1 000	Crossing another limestone belt
1 000	To Vernon av.— Fordham gneiss of unknown quality containing one fault zone
7 000	To Nott av.— Ravenswood grano-diorite — good rock
2 800	To Borden av.— Probably Ravenswood grano-diorite.
18 400	To Fort Greene Park Brooklyn — almost wholly unknown but contains probably 5000 or 6000 feet of poor ground

SUMMARY OF LINE C

Feet	
6 000	Yonkers gneiss — good quality
17 400	Fordham gneiss — good quality
6 800	Along contact between limestone and gneiss (questionable)
12 400	Inwood limestone — with several bad zones
6 400	Manhattan schist — probably good quality
3 000	Fordham gneiss — probably good quality
1 000	Fordham gneiss — unknown quality
9 800	Ravenswood grano-diorite — mostly very good rock
18 400	Almost wholly unknown
<hr/>	
81 200	total

Tabulated summary — Types of rock formations

	LINE A (WEST)		LINE B (CENTRAL)		LINE C (EAST)	
	Feet	Per cent	Feet	Per cent	Feet	Per cent
Yonkers gneiss	6 200	(7.2)	8 000	(9.4)	6 000	(7.3)
Fordham gneiss	7 000	(8.1)	13 000	(15.3)	21 400	(26.3)
Contact zones	4 400	(5.1)	0	(0)	6 800	(8.3)
Inwood limestone	12 000	(13.9)	21 400	(25.3)	12 400	(15.2)
Manhattan schist	50 200	(58.5)	36 200	(42.6)	6 400	(7.8)
Ravenswood grano-diorite .	0	(0)	0	(0)	9 800	(12.0)
Unknown	6 000	(7.0)	6 000	(7.0)	18 400	(22.6)
<hr/>						
Total length	85 800	.....	84 600	.....	81 200	.....

Summary of quality

	LINE A		LINE B		LINE C	
	Feet	Per cent	Feet	Per cent	Feet	Per cent
Good rock, 1st grade.....	42 400	(49.4)	33 800	(40.0)	39 800	(49.0)
Probably fair, 2d grade....	30 800	(35.9)	34 800	(41.1)	13 600	(16.7)
Probably poor, 3d grade....	6 600	(7.7)	10 000	(11.8)	9 400	(11.6)
Almost unknown	6 000	(7.0)	6 000	(7.1)	18 400	(22.7)
<hr/>						
	85 800	100.0	84 600	100.0	81 200	100.0

Argument on choice of line

In judging the quality of rock and its suitability for this conduit the factors of most weight are the same as those repeatedly mentioned in connection with other portions of the Catskill aqueduct line. That is, in brief, that the harder crystalline rocks of the Fordham gneiss and Manhattan schist types wherever known to be

free from fault crushing and surficial weathering are the best variety; that the more heavily buried areas of these rocks, together with those limestone areas that are known to be the most substantial of its class, should be regarded as fair or second grade; that the more obscure areas of limestone and all portions crossing faults or rivers or crush zones in any rock must be regarded as poor or third grade. This rating is based wholly on rock character and without any consideration of cost of construction.

From the above it is clear that line A has more "first grade" rock than either B or C and less "third grade" ground.

Line C has three times as much "unknown" ground as either B or C and less "first" and "second grade" rock.

In other words, the three lines are estimated:

	LINE A Per cent	LINE B Per cent	LINE C Per cent
First grade rock.....	49.4	40.0	49.0
Second grade rock.....	35.9	41.1	16.7
First and second grades together.....	85.3	81.0	65.7
Third grade rock.....	7.7	11.8	11.6
Unknown ground.....	7.0	7.1	22.7

In addition to these differences of quality, it appears from a study of the areal geology along the respective lines that a tunnel would pass across limestone contacts from one formation to another six times on line A, four times on line B, and seven times on line C. These may all be considered points of probable weakness.

All of the lines cross belts of well known weakness believed to represent fault zones. Line A crosses three such zones, line B crosses two, and line C crosses at least three.

Furthermore, all of the lines cut limestone for greater distances than seems desirable or necessary. The weakest ground and the most uncertain quality of ground that can be mapped falls within the limestone areas. In this respect line A with 13.9% of limestone ground is preferable to line B, with 25.3% or line C, with 15.2%.

From the above it is apparent that line C is least defensible. Line A has some advantage over both of the others, especially in quantity of first grade rock quantity of first and second grade together, low amount of the known poorest grade and small extent of the so called "unknown" ground.

The chief advantage of line A over line B lies in its much smaller limestone area (12,000 feet *vs.* 21,400 feet or 13.9% *vs.*

25.3%), and the chief advantage of line A over line C lies in its much smaller amount of "unknown" ground (6000 feet *vs.* 18,400 feet or 7.0% *vs.* 22.6%). On these grounds line A is the least objectionable of the three lines proposed.

But it is also clear from an examination of the field, as is shown on the accompanying map [pl. 32], that it is possible to avoid some of these objectionable features or certain parts of them and materially improve the figures by shifting the line to a sort of compromise position between line A and line B. This compromise line, or the trial lines from which the final tunnel line may result, should follow as closely as possible the gneiss and schist ridges and should avoid the limestone areas and known weak zones wherever possible.

Depth of tunnel

The rock formations in general at the required depths are no more objectionable on Manhattan island or in The Bronx than at other localities on the Southern aqueduct. There are weak places and crush zones to be crossed and some of them can not be avoided by any possible manipulation of the line, but these most questionable spots constitute but a small proportion of the whole distance. The depth most suitable must depend chiefly upon the depth necessary at the worst spots.

Comparative cost of construction if lines are shifted

The question is best answered by reference to the geological map. It will be noted especially that the belts of the different rock formations are usually narrow, and that they run nearly parallel to the average direction of the lines. Therefore a shift of line to no great distance would at many points place it within an entirely different formation. It is also notable that all of the lines run along or near the contacts between formations for long distances. At such points a very small shift would wholly change the type of rock and rock quality. Some shifting is desirable.

In general it may be assumed that the limestone belts would be easiest and cheapest to penetrate wherever they are fairly substantial, but they undoubtedly also contain the greater proportion of weak and troublesome ground and must be considered least desirable from the standpoint of maintenance and durability. The gneisses are probably most expensive to penetrate and the schists, medium. Both are more expensive than limestone but both are more likely to prove acceptable for other reasons.

The question of shifting the lines is a complicated one and hinges more upon rock conditions, durability, and location of weak zones, than on any possible cost.

Advisable changes in lines

None of the suggested lines are defensible from a geologic point of view for the reason that a much better one may be obtained by no very serious shifting.

In the general consideration of relative advantages of different possible locations of the line, it is believed that the following large features are of most immediate importance:

- 1 The ridges as opposed to the valleys.
- 2 The hard formations as opposed to the softer ones.
- 3 The crossing of few contacts as opposed to crossing many.
- 4 The location well within a formation as opposed to location along a contact zone.

It is distinctly preferable from a geologic standpoint (1) to follow the ridges, (2) to keep in the hard formations, (3) to avoid many changes from one formation to another, (4) to keep away from contact zones, and (5) to avoid weak zones, if possible, or cross known troublesome zones at the most advantageous point.

Recommendations of new lines F, G, H, I

The original lines A, B and C are marked on the map in blue [pl. 32]. In addition several trial lines are sketched in yellow, any one of which would give better geological conditions than any of the three original lines. The newly suggested trial lines differ from each other chiefly in the points at which they cross the limestone belts and weak zones. In all of them the central idea has been to follow the gneiss and schist ridges as persistently as possible. All unite at Central Park and are intended to follow Fifth avenue, Broadway, the Bowery and Market street to East river along one of the original lines. North of Central Park they differ from the original lines. The westerly one crosses the Harlem river at 176th street and may be designated line F. The easterly line may also cross the Harlem river at 176th street and may be designated line G; or it may continue southward and cross the Harlem at 155th street. It will then join the first one in the vicinity of 144th street and is called line H. The alternative easterly one which crosses the Harlem at 155th street and follows Seventh avenue to Central Park is line I.

Details of rock conditions along these lines are as follows:

Line F. (Westerly) beginning at Hill View reservoir

Feet	
7 600	Yonkers gneiss — good quality
15 000	Fordham gneiss — good quality
2 000	Fordham gneiss — probably 2d grade
1 200	Harlem river crossing — partly limestone — 3d grade
14 800	Manhattan schist — good quality
1 600	Manhattanville crossing — 3d grade — some limestone
2 600	Manhattan schist — good rock — through Morningside Park
800	At south end of Morningside Park — perhaps some limestone — 2d grade
1 400	Manhattan schist — good — to junction
12 000	Manhattan schist — along Central Park — good
20 600	To East river — Manhattan schist — less known ¹ — (fair) (2d grade)
6 000	To Brooklyn “ unknown ” ¹

85 600

Line G

Feet	
8 400	Yonkers gneiss — good rock
17 600	Fordham gneiss — good rock

which brings it to the Harlem river where the other line (F) is joined. Although the line is about 1400 feet longer, it avoids some low ground (2000 feet) along the east bank of the Harlem river, some of which may be in poor condition. Total length of line, 87,000 feet.

Line H

Feet	
8 400	Yonkers gneiss — good quality
23 800	Fordham gneiss — good quality — to Harlem river
1 000	Crossing Harlem river — probably fault zone in gneiss
800	Fordham gneiss — good quality
1 000	Limestone — 2d grade
1 200	Manhattan schist — good quality — to junction with the first line (F) at 145th street

From this point the line is the same as F and G. Its chief advantage is the great distance which it has in Fordham gneiss.

Total length of line, 85,600 feet.

¹Subsequent explorations made by the Board of Water Supply have eliminated this unknown ground. See later discussion.

Line I

Feet	
8 400	Yonkers gneiss — good quality
23 800	Fordham gneiss — good quality — to Harlem river
1 000	Crossing Harlem river — probably fault zone in gneiss
4 400	Fordham gneiss — good rock — to 135th street
4 600	Inwood limestone — probably fair — 2d grade
2 000	Inwood limestone — probably poor quality — 3d grade
1 000	Manhattan schist — good quality

At this point the line unites with line F. Total length of line, 83,800 feet.

A tabulation of these figures indicating estimated extent of rock types is given below:

	LINE F Feet	LINE G Feet	LINE H Feet	LINE I Feet
Total length of line.....	85 600	87 000	85 600	83 800
Length in Yonkers gneiss.....	7 600	8 400	8 400	8 400
Length in Fordham gneiss.....	17 000	17 600	25 600	29 200
Length in Inwood limestone and marginal contacts.....	3 600	3 600	3 400	6 600
Length in Manhattan schist.....	51 400	51 400	42 200	33 600

Comparative summary of types of formation (Comparative distances are expressed in percentages)

	A	B	C	F	G	H	I
Yonkers gneiss	7.2	9.4	7.3	8.8	9.6	9.8	10.0
Fordham gneiss	8.1	15.3	26.3	19.8	20.2	29.9	34.8
Contact zones.....	5.1	0.0	8.3	4.2	4.1	3.9	7.8
Inwood limestone	13.9	25.3	15.2				
Manhattan schist	58.5	42.6	7.8	60.0	59.0	49.3	40.1
Ravenswood grano-diorite ¹	0.0	0.0	12.0	0.0	0.0	0.0	0.0
Too little known to classify ¹	7.0	7.0	22.6	7.0	6.9	7.0	7.1

¹The Ravenswood granodiorite has been proven by later explorations to extend into the territory here marked as too little known to classify.

As a group it is especially noticeable that the new lines F, G, H, I, have a very much lower percentage of contact zones and limestone. The percentages of gneisses have been notably increased, and the unknown and questionable formations have been reduced to approximately the lowest terms.

Estimated summary of quality

	LINE F Feet	LINE G Feet	LINE H Feet	LINE I Feet
Good rock, first grade	53 400	56 800	54 600	49 600
Fair " second "	23 400	21 400	22 400	25 200
Poor " third "	2 800	2 800	2 600	3 000
Unknown ¹ (Brooklyn)	6 000	6 000	6 000	6 000
	85 600	87 000	85 600	83 800

¹ All of this rock is now known to be of good quality.

In other words these new lines show:

	LINE F Per cent	LINE G Per cent	LINE H Per cent	LINE I Per cent
First grade rock	62.3	65.3	63.8	59.1
Second "	27.3	24.6	26.1	30.0
First and second grades together.....	89.6	89.9	89.9	89.1
Third grade rock.....	3.2	3.0	3.0	3.6
" Unknown " ground ¹	7.0	6.9	7.0	7.1

¹ Results of recent boring explorations show that this ground is first grade also.

A comparison on this basis with the original lines A, B, C indicates that these new lines F, G, H, I, make a better showing, especially on first grade rock and that all show decided reduction in the third grade ground.

	A	B	C	F	G	H	I
First grade rock.....	49.4	40.0	49.0	62.3	65.3	63.8	59.1
Second grade rock	35.9	41.1	16.7	27.3	24.6	26.1	30.0
First and second	85.3	81.0	65.7	89.6	89.9	89.9	89.1
Third grade rock.....	7.7	11.8	11.6	3.2	3.0	3.0	3.6
Unknown ¹	7.0	7.1	22.7	7.0	6.9	7.0	7.1

¹ Now known to be first grade.

On geological grounds, therefore, it is confidently believed that any one of the new lines (F, G, H, I) would give decidedly better results than any one of the original ones (A, B, C). The poor and the questionable and the unknown ground can not be wholly avoided by any possible line, no matter how roundabout. In these lines, approximately as drawn, the objectionable points are reduced to a minimum with almost no increase in total length of conduit. The objectionable portions are also restricted in large part to the

Harlem river, where we already have the experience of the last aqueduct (the New Croton aqueduct) as a guide, and a very few other spots.

General conclusions

Line I is the shortest possible defensible line. Its chief objectionable feature is a rather long stretch, 6600 feet of limestone, from 135th street to Central Park, upon the quality of which there are no data. It crosses the Harlem river fault probably in gneiss. But it crosses the extension of the Manhattanville fault in limestone.

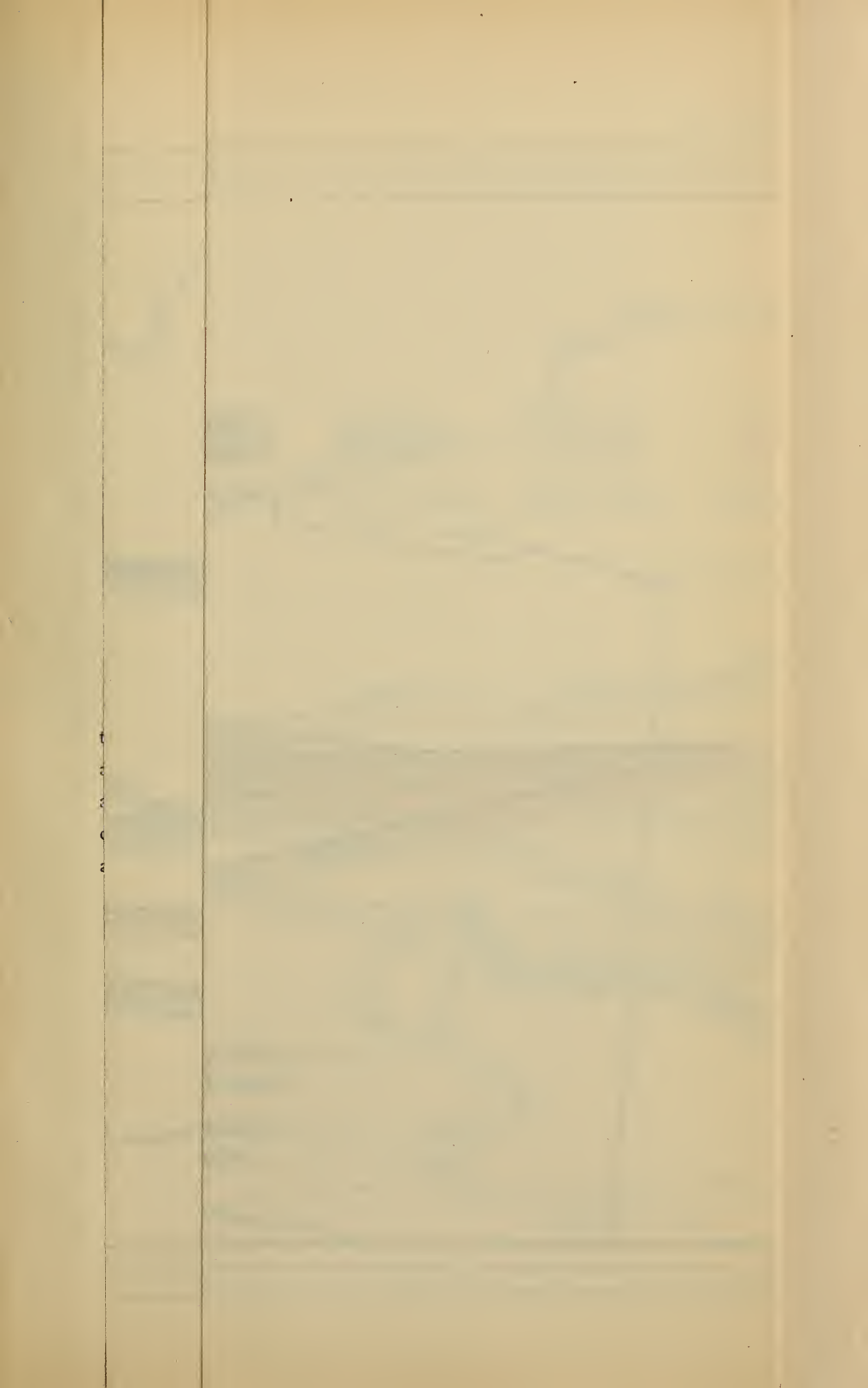
Lines F, G and H are almost equally defensible. Line G is longest, but is in some respects — especially in following the ridge crests — one of the best possible locations.

It should be appreciated that many other matters, such as municipal works already completed or projected, or matters of engineering practice, are likely to make it necessary to modify any line proposed, and that the final line is more likely to be a compromise, considering all interests.

A graphic representation of the comparative merits of the proposed lines is given in plate 33. This is strictly a geologic study. The lines are properly placed on an outline map of the city corresponding exactly to those drawn on the geologic map, plate 32. The geologic formations that each would cut are represented on longitudinal sections which follow each line, and the attitude and structure of each formation are indicated.

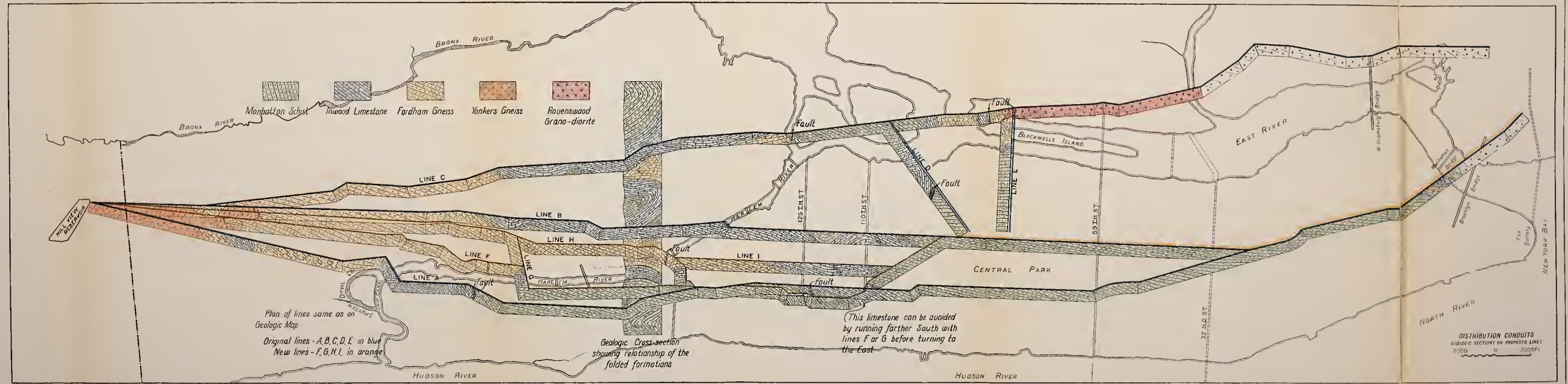
Revised lines

Subsequently two revised lines based upon the preceding studies were examined to determine preference. Later one of these, or a slight modification of it, was adopted as the one to be explored. It was soon determined on the same reasoning as was applied to the first group of lines that the most westerly line — the line keeping as much as possible within the gneiss and schist ridges — would be the most likely to give satisfactory conditions. By this method of selection the unknown or untested and doubtful ground was reduced to its lowest limits. It was found that nearly all of the very weak spots could be located by inspection in the northern portion of the line, but south of 59th street the question is decidedly more difficult because of the heavy drift cover. No rock outcrops occur south of 30th street, and one is reduced to the evidence of deep borings.



GRAPHIC GEOLOGIC STUDY
OF THE
ALTERNATIVE LINES
FOR THE
NEW YORK CITY
DISTRIBUTION CONDUIT

The attitude of the different formations and their approximate amounts are indicated by longitudinal sections along the alternative lines whose courses are indicated in detail on the accompanying geologic map.



Points for exploration north of 59th street

It was soon evident that extensive exploratory work would have to be undertaken and the following points were selected at which to begin.

1 The Harlem river crossing, where the distribution conduit line crosses the river just below High Bridge [*see* later description]. The only good evidence as to character of rock at this place is from the pressure tunnel of the New Croton aqueduct which crosses the river a short distance above.

2 The Manhattanville cross valley (125th street depression). This is the most important cross depression on the island of Manhattan. It is apparent after a little investigation that the bed rock floor lies deep and that if it were not for the drift filling the tides would surge through this valley making a direct connection between the Hudson and East river. It was the least known as to depth and character of any point along the proposed line.

3 The depression between Morningside and Central Park. At that place limestone on the crest of a pitching anticline reaches farther south than on either side and is more deeply eroded. The other zones of large importance are in southern Manhattan the geology of which is a special study.

CHAPTER XVIII

AREAL AND STRUCTURAL GEOLOGY SOUTH OF 59TH STREET

The necessity for exploration in certain sections of this area can not be appreciated without a statement of the local geology and especially of the revision of both areal and structural geology that the writer has based upon an exhaustive study of all the available drill cores and other data to be found in southern Manhattan, East river and Brooklyn.

Below Central Park there is now little geology to be gathered from a study of the present surface. But as far south as 31st street the bed rock geology is pretty well known from earlier reports and from recent improvements that have exposed the underlying rock. All of this portion is mapped as Manhattan schist except one small area of serpentine at 59th street between 10th and 11th avenues. There is no reason to modify this usage. A careful study of a great number of rock borings from the Pennsylvania Railroad tunnel across Manhattan at 32d street proves beyond question that bed rock is Manhattan schist, including almost all known variations and accompaniments, for the whole width of the island along that line.

Still farther southward the points that have yielded exact information about bed rock are less numerous, and below 14th street are confined to deep borings or an occasional very deep excavation for foundations. Even these sources of information are lacking over large areas. The greater number of borings available are along the water front. Their distribution is such as to indicate that the west side and central portion and southerly extremity of the island are all underlain by Manhattan schist. This is true eastward to the East river at 27th street, and as far eastward as Tompkins square at 10th street and almost to the Manhattan tower of Brooklyn bridge in that vicinity.

To the eastward of these limits, i. e. to the eastward of the line projected from Blackwell's Island to the Manhattan tower of Brooklyn bridge, there is a more complicated geology. The borings of the East river water front are decidedly variable. They are certainly not all Manhattan schist of the usual types. Those most unlike the Manhattan are at the same time most like some varieties

of the Fordham, and indicate that these formations both occur. The lack of any data in the beginning of this investigation except on the water front made it impossible to draw more than very general lines. Drawn in this way, the lines of course are too straight, but it is certain that they indicate more nearly the actual existing areal distribution of formations than any of the maps now in existence.¹ They indicate a southward extension of the Blackwell's Island belt of Fordham gneiss toward the Manhattan tower of Brooklyn bridge. How much of this anticlinal fold of Fordham actually brings this formation to the surface it is impossible to say, but that it may be expected to be encountered along this line is evident.

On the east side a parallel belt of Inwood limestone is indicated and this again is succeeded by a Fordham gneiss area which occupies the rest of the eastern margin. Explorations made along the line of the gas tunnel across East river at 72d street² indicates comparatively narrow belts of limestone there in both the east and west channels. The limited width of limestone at these points, together with the occurrence of two strongly developed disintegration zones, seem to indicate rather extensive squeezing out and faulting of this formation along fault planes

¹In the summer of 1908 the writer was assigned the task of studying in detail the evidences of geologic structure beneath the drift in southern Manhattan. Before any drilling was attempted in the city by the Board of Water Supply, a thorough canvass was made of all previous borings in this district and the cores and records were personally inspected. More than 300 such borings were found in which some of the core could be secured for identification and classification as to formation and condition. Most borings were given no weight at all in the final summary of this evidence unless the rock core or at least fragments of it could be secured. After all of these newly assembled data were tabulated and plotted on the map, it was evident that if the identifications were correct the areal and structural map of southern Manhattan needed extensive revision. A new map therefore was made and presented to the chief engineer of the Board, October 30, 1908. This has been used since as the basis for exploration of the Lower East Side section. This original tabulation and map only slightly modified was published under the *Areal and Structural Geology of Southern Manhattan Island* [N. Y. Acad. Sci. Annals, April 1910, v. 19, no. 11, pt 2]. The extensive explorations of the board have made further revision necessary [see accompanying map, pl. 34]. Exploratory boring is still in progress (October 1910) and some slight modifications of boundary lines may yet be made.

²This is taken from Prof. J. F. Kemp's description of *The Geologic Section of the East River at Seventieth Street, New York* [N. Y. Acad. Sci. Trans. 1895. 14:273-76].



Base map reproduced from a copyrighted map by E. Belcher Hyde, 5 Beekman street, and here used by permission

REVISED AREAL GEOLOGY OF SOUTHERN MANHATTAN ISLAND AND THE ADJACENT MARGIN OF LONG ISLAND

This revision is based upon exploratory borings to June 25th, 1910. The heavy blue line marks the course of the proposed pressure tunnel intended to carry the Catskill water to Brooklyn

parallel to the strike. Such movements are capable of cutting out the intermediate limestone entirely from between the schist and gneiss. How much of such modification exists, in the almost total lack of data bearing upon the question, it is impossible to say. The intermediate belt is indicated on the accompanying map [pl. 34], as a limestone area. At one point at least the limestone does occur in the older borings, i. e. on the southeastern margin of the Manhattan pier of the Manhattan bridge (bridge no. 3), at the foot of Pike street.

On the Brooklyn side no formations of this series except the Fordham and its associated igneous masses, such as the Ravenswood granodiorite, have been identified within the area under study. Limestone is reported (Hobbs reference to Veatch) near Newtown creek, a little beyond the eastern margin of the present map.

Structure of the East river area

Manhattan side. In all of the area south of 59th street, structural features are even more obscure than the areal geology.

There is no reasonable doubt but that weak zones will be found as frequently in the Manhattan schist portion of this area as on the line north of 59th street, but they can not be indicated as closely. No cross fault of large consequence can be identified, but there is some evidence of a minor zone that should be encountered on Fifth avenue, in the vicinity of 32d street. The Pennsylvania tunnels and the subway both cross this line and so far as known there were no serious weaknesses developed. There is nowhere any evidence of an important depression like the Manhattanville valley.

It is confidently believed that the problems on this southerly portion of Manhattan are involved chiefly with the longitudinal structures produced by folding and faulting and subsequent disintegration along such zones.

Crossing of East river

From 59th street to the East river there seems to be no reason for a preference between the two lines P and Q.¹ On the Brooklyn side likewise there is no known geological reason for preference. Such basis for choice as is now known relates to the East river channel alone. Since this is at the same time the most difficult section of the line to explore and probably the most uncertain section to estimate as to condition and consequent depth of tunnel, it would be especially useful to be able to make a decisive selection of crossings at once.

¹ For location of these lines *see* map, pl. 32.

Such evidence as has any bearing upon this question has already been used in formulating the interpretation of geologic structure given in the foregoing sections of this report. If the succession and boundaries of formations as outlined are reasonably close to the actual conditions, it would appear that line P (the southerly one just above Manhattan bridge) has some advantage over line Q (near Williamsburg bridge). The chief elements in this advantage are as follows:

1 It would appear that line P might lie wholly within the Fordham gneiss in the East river section, while line Q may cross two contacts.

2 From the evidence of borings made in the East river at 14th street¹ it appears probable that a belt of schist similar to Manhattan schist in quality (whether accompanied by limestone or not there is no direct evidence) lies in the river channel toward the east side and in all probability extends southward in the middle of the river at Williamsburg bridge. This would be cut by line Q. The uncertainties of this association are of sufficient importance to throw the balance of present choice toward line P.

3 If the theory that the East river course is due chiefly to zones of weakness following fractures or faults is true, their possible comparative condition as they cut through different formations must be taken into account. There is little doubt on this point but that, in zones of similar original disturbance, those in the Fordham gneiss have suffered less extensively from disintegration than those cutting either the limestone or schist. Therefore, obscure as it may be, the preference is again in favor of line P.

4 If, furthermore, the course of the river is due to cross faulting or any similar or related displacements or movements, an inspection of the structural map indicates that the controlling zone followed by the river as it crosses line Q must have a general strike northwest, while the corresponding zone that crosses line P strikes east. Of these two types (directions) of fault zones, so far as they may be judged to have influence in the adjacent area, there is no doubt but that the northwest type (the set that has a northwest strike) is both the more common and the more important. If this general tendency is also true here, then on this account also line P may be considered slightly more favored. In reality not much weight can

¹ These borings were made by the Public Service Commission in explorations for subways.

be given to this point since the condition of these faults is not fully known.

5 If, as may well happen, the present East river is displaced¹ from its old channel by glacial drift, so that it is essentially an evicted stream, there may not be as pronounced a channel or as weak ground to cross at such points as at those where the old channel is still occupied. In such case both of these lines are favorable.

6 On the other hand, the crossing of line P is almost a mile nearer to the great Hudson gorges, to which doubtless this portion of the preglacial East river was tributary, and consequently its bed rock channel, if it is the real preglacial channel, may be expected to be deeper and the accompanying disintegration (so far as it may be controlled by this factor) may be expected to reach lower than at points in similar surroundings farther up stream. It is impossible to say how much weight should be given to this objection. It does not seem to be of sufficient importance to fully offset the favorable features indicated in items 1, 2, 3 and 4.

On the basis of these studies line P (the southerly one) near Manhattan bridge was chosen as the site of preliminary exploration promising the most favorable results. Later this was shifted a short distance without introducing any new conditions.

¹ Exploratory borings indicate that such has been the history of the river.

CHAPTER XIX

SPECIAL EXPLORATION ZONES

Exploration by borings¹ and other methods have been made at all questionable or uncertain points along the line. As was expected in the beginning five places have required elaborate exploration and some exceptional conditions have been proven. The original geological investigation based upon surface study as outlined in the foregoing pages served to locate these spots accurately.

These places or zones, now either finished or sufficiently well known to permit accurate statement of geologic conditions, are as follows:

1 The Harlem river crossing at 167th street, where the aqueduct will cross from a ridge of Fordham gneiss beneath the Harlem river, where the whole thickness of Inwood limestone will be cut, to the ridge of Manhattan schist above the Speedway on Manhattan island.

2 The Manhattanville cross valley, a low pass crossing the island at about 125th street. The part explored extends from St Nicholas to Morningside Parks and crosses a zone with very low rock floor in the Manhattan schist.

3 From Morningside to Central Parks. The line crosses the strike of the formations at this point and cuts a longitudinal fault and anticlinal fold which tends to bring the Inwood limestone within surface influence.

¹ Exploratory work has been in direct charge of Mr T. C. Atwood, division engineer, who has followed all stages of it almost from the beginning. In the later exploratory work an immense amount of detail and a very complex lot of data has accumulated requiring constantly the services of a man with some special geological training. Mr John R. Healey, formerly in the testing laboratory, was transferred to this special field. He is probably more familiar with the multitude of details resulting from boring operations along the conduit line than any one else. Except for the care and good judgment used by these men in preserving data, and the wisdom of the men who planned the line and methods of work before them, much valuable geologic data would have been lost. Notwithstanding the best efforts of the consulting geologist some really critical points escape unless some one constantly on the ground is directly interested in them as a part of the regular responsibility.

4 The Lower East Side zone. On Delancey street east of the Bowery, the line crosses the structure and at this point the whole series of crystalline formations appears. Besides complicated structure there is also exceptionally deep alternation or decay of bed rock.

5 The East river crossing — from the foot of Clinton street to Bridge street, Brooklyn.

1 Harlem river crossing

Geologically the Harlem river between 155th and 200th streets has the same relation to local formations for the whole distance. It flows on the Inwood limestone bed which stands almost exactly on edge, while the east river-bluff is formed by the underlying Fordham gneiss, and the west, by a strong escarpment of Manhattan schist which extends southward throughout the whole of Manhattan forming the backbone of the island.

At the selected crossing a short distance below High Bridge, near 167th street, the schist-limestone contact is in the river and appears to be a low weak spot [*see* detail of record]. The limestone-gneiss contact however is in the flat east of the river bank, near Sedgwick avenue and seems to be more substantial. The structural detail and relations are shown on the accompanying profile and cross section, [pl. 35].

It is observed by examination of the data secured by borings that the limestone formation at this point is exceptionally heavily impregnated with pegmatite dikes and stringers, and that interbedded schist layers are large and numerous.

The weakest spot found lies at the contact between schist and limestone where there is probably some longitudinal displacement.

A similar condition was found at the new Croton crossing 2000 feet farther north. On the whole bad decay does not extend very deep — 150–200 feet.

Several borings have been made and on them is based the only judgment possible of the actual structure and physical condition of rock. In most cases the evidence is easily interpreted for these points. The most weakened spot, as well as the most difficult to interpret in all its detail, is the limestone-schist contact. It is judged that hole no. 17 cut through this contact zone. This boring is located in the river 50 feet from the Speedway (west bank) on the proposed tunnel line which crosses a short distance south of High Bridge. It is known as hole no. 17/C38. Because of the

somewhat unusual quality of material at this place as indicated by the wash and core saved and because of the suggestion it gives

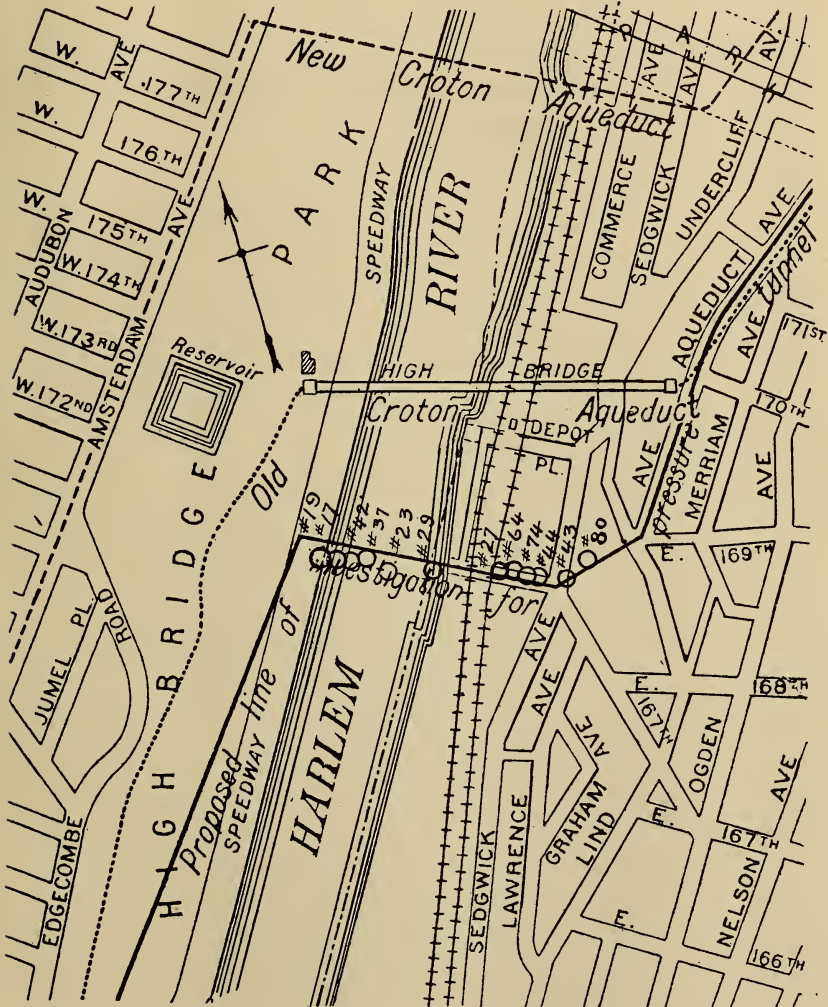


Fig. 38 Key map showing plan of exploratory borings at the Harlem river crossing, location of the New Croton aqueduct which crosses the Harlem in a pressure tunnel and the Old Croton aqueduct which crosses the river on High Bridge

about the structure and condition of rock beneath the river, the record and interpretation notes are given.

- Feet
- 0—13=Water
- 13—46=Black river mud (mostly river silt)
- 46—48=Sand with decayed wood (peaty wood)
- 48—70=Quartz and garnet sand rather clean (glacial)
- 46—70=Lumps of peaty matter coming to the surface at intervals indicating occasional small layers of peat (glacial)
- 70—78=Mixed sand (glacial)
- 92 =A core of Triassic contact shale (a drift boulder from the Palisade margin). At this point also a piece of Manhattan schist (boulder)
- 95 =4 pieces of diabase (Palisade trap) from another drift boulder
- 96.5 =5 pieces of Inwood limestone (boulder) followed by a piece of quartzite and several mixed pebbles indicating glacial drift origin
- 114—119=A buff yellow sand with much pearly yellow mica flakes. Effervesces with acid. This shows no foreign matter. It is chiefly residuary decayed rock in place and represents silicious and micaceous limestone. It is decayed, very impure, Inwood limestone
- 119 =Clay with pieces of flinty quartzite, probably from a small quartzose seam in the limestone
- 120—126=Light flaky yellow material. Much pearly mica with earthy matter. Effervesces in acid. Residuary from Inwood limestone
- 128 =White and drab lumpy residuary matter (kaolin) and earthy substances. Effervesces. A more impure Inwood. Also shows several pieces of core of a porous, rotten limestone. Inwood
- 129—134=Reddish brown lumps. Effervesces a very little. Mostly clay but still no foreign matter. Residuary material from a more silicious bed. A few pieces of hard, impure limestone at 133 feet
- 134 =Pieces of a porous quartz chlorite rock with little lime. Is a leached quartzose rock evidently a sandstone layer in the limestone. Rock belongs to the Inwood formation

Feet

- 135—143=Dark micaceous matter containing chiefly biotite, a pearly mica, and quartz. Rock is a decayed schist bed—the transition between Inwood limestone and Manhattan schist
- 143—151=Dark brown micaceous material. Biotite and quartz — chiefly. Rock is decayed schist (transition rock). At 146 feet encountered pieces of a pegmatite veinlet. All pieces except 1 are pegmatitic — the other one is calcareous sandstone, fallen into this lot from the 134 foot level
- 151—160=Chunks of pegmatite (a vein rock)
- 151—161=The mica washings continue the same as at 143—151 feet. Rock is a transition schist with pegmatite stringers
- 164—169=Brownish yellow micaceous matter (loose). Mica, quartz, chlorite, lime. Effervesces
- 164—173=Many pieces of typical Manhattan schist. A fair amount of core for the conditions. Rock is not so badly decayed but is broken into small pieces. Rock is Manhattan schist of typical character.

Summary

- 1 The material is chiefly river silt down to 46 feet
- 2 Lighter glacial deposits 46—78 feet
- 3 Heavy bouldery drift 78—97 feet
- 4 Uncertain (insufficient data) 97—114 feet
- 5 Residuary micaceous decay products from Inwood limestone 114—135 feet
- 6 Decayed transition schist bed with some lime, but chiefly like the Manhattan schist 135—161 feet
- 7 More calcareous schist 161—164 feet
- 8 Typical Manhattan schist 164—173 feet

Interpretation

- 1 Foreign matters, glacial and recent deposits, continue to a depth of between 97 and 114 feet.
- 2 Rotten formations (residuary matter) in place begin at least as high as 114 feet. There is no foreign material below that point except grains that have fallen into the hole from above.

- 3 More solid rock begins at 164 feet.
- 4 The upper portion of the rotten rock (114-35 feet) is calcareous enough to belong to the Inwood limestone formation. The lower 9 feet (164-73 feet) is typical Manhattan schist. The intermediate ground 135-64 feet is transition variety.
- 5 The drill has cut the contact between Inwood and Manhattan formation.
- 6 If this identification of the badly decayed matter is correct, the contact at this point dips steeply eastward, i. e. it is overturned.
- 7 Both types of rock are shown to be extensively decayed.
- 8 The worst (deepest) decay zone probably lies still a little farther east, and follows the dip of the micaceous limestone near the contact.

These conditions are indicated on the accompanying cross section [see pl. 35].

The conditions indicated by this one hole are consistent with those known for the New Croton aqueduct tunnel 2000 feet farther north where, according to the engineers' drawings, the formations also are overturned. Fifty feet of decayed rock is shown in this hole. The contact is undoubtedly decayed considerably to a depth of more than 200 feet below water level.

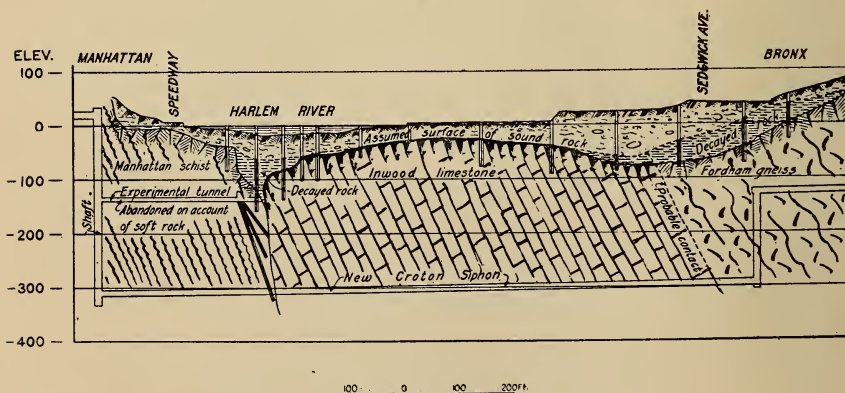
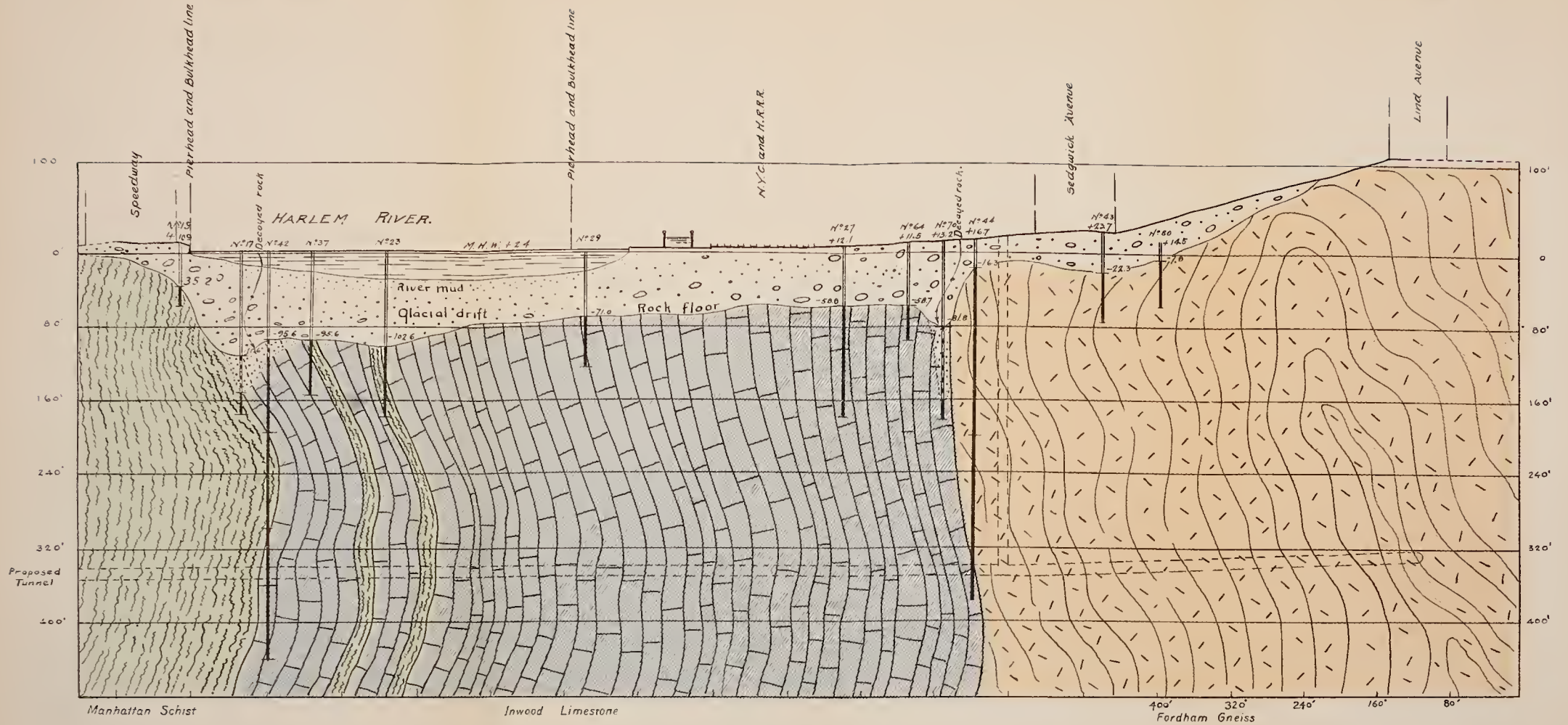


Fig. 39 Harlem river crossing—New Croton aqueduct

Another boring put down to test conditions at still greater depth nearby explored the rock to -442.7 feet. Because of the information it gives about the deeper bed rock, a summary of the record based upon examination of the material is given:

Propo
Tunn



Geologic cross section and graphic interpretation of the exploratory borings made for the New York City Board of Water Supply at the site of the proposed pressure tunnel beneath the Harlem river, reaching Manhattan at the foot of 171st street

Hole no. 42 (75 feet from Speedway, 25 feet east of hole no. 17)

Feet		
0	to -94.1	River muds and various types of drift similar to hole no. 17
-94	to -96	Iron cemented sand — both drift sand and local angular material
-98	to -127	Micaceous clay — residuary decayed matter — with choppings of calcite, quartz, mica and chlorite representing weathered Inwood limestone
-127	to -135	Core — Inwood limestone (impure)
-135	to -149.5	Pegmatite
-149.5	to -197	Inwood limestone — typical — standing almost vertical in upper portion but changing to about 45° and farther down to 60°. Good sound rock
-197	to -241	Manhattan schist — of typical sort — and in sound condition, but becoming somewhat more broken and altered near the bottom. Dip about 60°–80° and even more. Average probably 75°–80°
-241	to -295	Manhattan schist — typical — dip variable but mostly above 70° to vertical — some pegmatite — fractures are at high angle. Rock sound
-295	to -302.5	Pegmatite
-302.5	to -442.7	Inwood limestone — typical — good quality — dip 70° to very flat — one piece not over 35° but mostly obscure

An interpretation summary is as follows:

Feet		
0	to -94	River muds and drift filling (glacial and recent)
-94	to -96	Transition to residuary matter
-96	to -127	Residuary matter and badly decayed Inwood limestone
-127	to -197	Inwood limestone
-197	to -302	Manhattan schist
-302	to -442.7	Inwood limestone

Geologic cross section. The accompanying cross section [pl. 35] embodies an interpretation of all the data secured in the Harlem river. It is now known that the limestone is overturned

slightly at both contacts. The nature of these contacts makes it seem probable that there is very little of the limestone squeezed or cut out by movement. Therefore this crossing gives a fairly accurate measure of the thickness of the Inwood. This is approximately 750 feet. No section about New York city is more accurately determined.

2 Manhattanville cross valley

In northern Manhattan the schist ridge which forms the backbone of the island and has a relief of more than 100 feet, is cut across by a prominent valley that extends from the Hudson at 130th street eastward to the Harlem Flats and East river. This valley is nowhere more than 25 or 30 feet above the sea level and is drift filled. Previous to the recent boring explorations of the Board of Water Supply its true depth to rock floor was unknown. The few borings recorded, however, indicated a depth of more than a hundred feet. One such boring at 129th street and Amsterdam avenue is reported as penetrating 109 feet from surface without touching rock. Another of similar results is located at 125th and Manhattan streets where a depth of 204 feet failed to touch rock.

Besides determining rock floor in the present case, it was important to determine rock structure and conditions. It appears from surface features that this cross valley probably follows a fault zone along which there has been weakening of the rock and consequent disintegration and decay. If this is so it would be advantageous to find the limits of it and determine what displacement effects were produced. It has been surmised by all students of local geology that such cross faults may lift the blocks on the south side of them, one of the chief indications being the fact that in spite of a strong southerly pitch in all the formations they do not rapidly disappear below sea level.

The accompanying profile and explanatory section indicates the principal results of exploration [see pl. 36]. Badly crushed ground has been found in the holes near the north end of Morning-side Park but the rock, when found, is not very badly decayed. The rock floor is very low, almost 200 feet below sea level at the lowest. It appears that if the drift were stripped off from this valley the Hudson and Long Island sound would unite across the Harlem Flats and Manhattanville forming a channel and outlet much deeper than the present East river course.

The glacial drift of this valley is prevailingly fine modified drift some of which is probably stratified and fairly well assorted.

This is more strikingly true of the southerly extension of this low ground southward along Morningside Park. A very deep and prominent preglacial stream came down from the gap between Morningside and Central Parks.

It is not yet proven that the fault has really raised the Morningside block. At least if there is such displacement it is not of sufficient amount to bring up a different formation at any point yet examined. It would be possible for the limestone to be brought up to the surface, but except for a few pieces of interbedded limestone no evidence has been secured. The occurrence of this, however, is thought to indicate proximity to the limestone contact.

General geologic conditions established. Fourteen borings have been made for the special purpose of determining exact conditions. On the data of these holes there are several features now established beyond question that were originally given only as probabilities. The most important of these may be enumerated as follows:

1 A very deep cross valley is now proven between 123d and 126th streets, and its profile can be plotted.

2 A part of this ground is badly broken, as if belonging to a fault zone, but most of the floor thus far tested is not in bad condition, i. e. it is not very badly crushed or decayed.

3 The drift cover in this cross valley is more than 200 feet deep over a distance of more than two blocks on the proposed line (from 123d street to Manhattan street).

4 The limestone contact lies more than 300 feet east of the proposed line at this Manhattanville cross valley.

5 At 121st street the limestone-schist contact stands very steep and is probably slightly overturned. This is indicated by the data of hole no. 33.

6 The contact line approaches nearer to Morningside Park in passing southward, touching the park between 110th and 113th streets and the contact is probably not overturned in this southerly extension.

3 Morningside to Central Parks

The contact between Inwood limestone and Manhattan schist follows nearly parallel with the Morningside Park boundary on the east side, but, because of its form, actually touches the park only at the southern end between 110th and 113th streets. At the north end it lies off more than half a block to the east. The Manhattan schist forms an escarpment because of its more resistant

character and this eastward facing cliff and slope forms Morningside Park. St Nicholas Park, farther north, from 128th to 155th streets has the same structural relations. In both cases the present escarpment stands back from 200 to 500 feet from the actual contact.

As the formations all pitch southward and are pretty closely folded, the higher formations gradually appear and at 110th street another parallel ridge of Manhattan comes in above the limestone in the trough of the next syncline to the east. This forms the north end of Central Park and from this point southward Manhattan schist is continuous. But between the Morningside belt of schist and the Central Park belt at 110th street lies an anticline of Inwood limestone also pitching southward and gradually passing beneath the schist which encroaches upon it in a long wedge until a few blocks farther south it passes wholly beneath the schist, which from that point is continuous.

This anticlinal wedge and its accompanying structures and rock condition was the subject of some detailed exploration.

The records of a few drill holes together with an interpretation of all the data will serve for the present purpose.

The most important borings are summarized below:

a Hole no. 3 on 113th street, 232 feet east of Morningside Park East

Surface elevation+42.6 feet

Rock floor at depth of 81.5 feet=el. -38.9 feet.

Material:

0-19 feet—to el.+23.6 feet=soil and mixed drift

19-79 feet—to el. -36.9 feet=modified drift. Assorted sands and silts

81.5-94.58 feet—to el. -54 feet=Inwood limestone. Typical and in good condition

b Hole no. 7. On 113th street, corner of Manhattan avenue

Surface elevation+38 feet

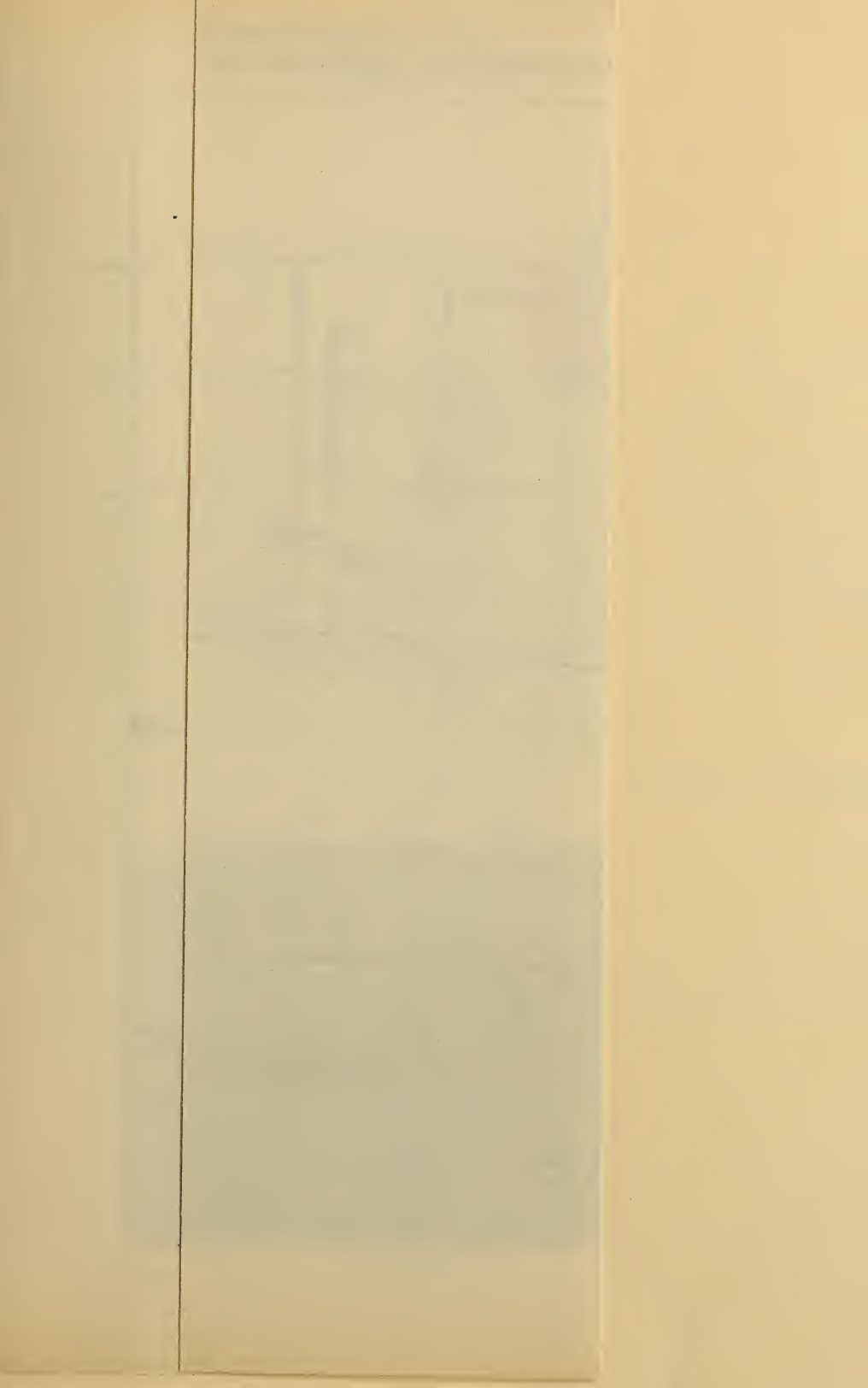
Rock floor at depth of approximately 165 feet=el. -127 feet

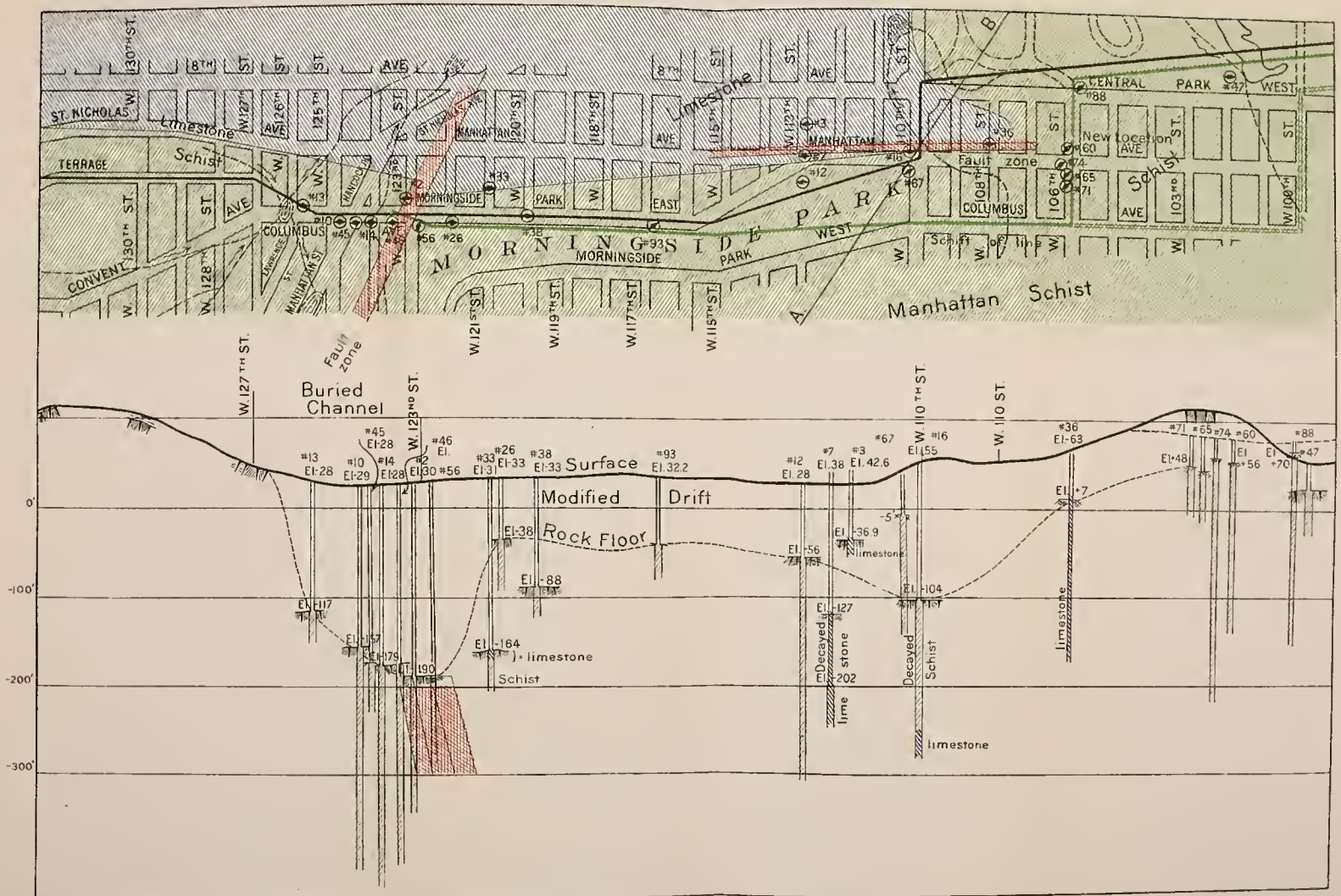
Material:

0-85 feet—to el. -47 feet=modified drift

85-165 feet—to el. -127 feet=sand with much more clay, part of which may be decayed rock

165-240 feet—to el. -202 feet=disintegrated rock ledge. Some micaceous type believed to be the transitional facies of the schist-limestone contact





Geologic detail of the Manhattanville-Morningside section showing the alternative lines studied, the locations of exploratory borings, the two principal crush zones and longitudinal profiles

242-280.71 feet=to el. -242.71 feet=Inwood, very coarse type of limestone. Poor core showing. Much broken

c Hole no. 12. In Morningside Park at 113th street

Surface elevation+28 feet

Rock floor at depth of 84 feet=el. -50 feet

Material:

0-26 feet=to el.+2 feet=mixed drift

26-84 feet=to el.-56 feet=modified drift

84-335.15 feet=to el.-307.15 feet=Manhattan schist, typical with considerable pegmatite. But all good sound rock, not much broken and standing at about 65°-80°

d Hole no. 16. Corner of Manhattan avenue and 110th street

Surface elevation=+55 feet

Rock floor at depth of 159 feet=el.-104 feet

Material:

0-44 feet=to el.+11 feet=filled ground and mixed material

44-159 feet=to el.-104 feet=fine sands and silts interpreted as chiefly modified drift. Much of it very fine and the lower portion rather micaceous and angular throwing a little doubt on the exact line of demarcation between drift and residuary matter

159-161 feet=to el.-106 feet=core of Manhattan schist

171-186 feet=to el.-131 feet=decayed rock in place, some micaceous type, coming out as mud

186-228 feet=to el.-173 feet=micaceous reddish mud with variable amounts of angular quartz grains. Certainly residuary decayed rock

228-270 feet=to el.-215 feet=similar residuary matter less highly colored passing from reds into grays and coming out as soft material

270-305 feet=to el.-250 feet=grayish micaceous and quartzose residuary matters. With much silvery mica and chloritic grains near the bottom

305-335 feet=to el.-280 feet=Inwood limestone, *core*, ordinary type. No more recovered above this point except for 2 feet between 159 and 161 feet

e Hole no. 36 at 108th street and Manhattan avenue

Elevation of surface+63 feet

Rock floor (decayed) at depth of 55 feet=el.+8 feet

Depth to solid core=248 feet=el.-185 feet

Material:

- 0-55 feet=el.+8 feet=modified drift (fine silts)
 55-155 feet=to-108 feet=micaceous soft material with
 broken sand=decayed micaceous rock
 155-215 feet=to-152 feet=reddish mud of similar constitu-
 ents. Is decayed rock colored by iron
 215-240 feet=to-177 feet=transition to more grayish and
 greenish soft matter
 240-245 feet=to-182 feet=greenish mica rock=a decayed
 chlorite, mica quartz, schist layer
 248.33-254.25 feet=from el.-185.35 to-191.25 feet=chloritic
 Inwood limestone

A summary of these data gives:

- 0-55 feet=drift
 55-245 feet=decayed rock ledge
 248-254 feet=solid rock ledge (limestone)
- f Hole no. 2 at 123d street, 100 feet east of Morningside Park East
 Surface elevation+30 feet
 Rock floor at depth of 220 feet=el.-190 feet

Material:

- 0-13 feet=to el.+17 feet=soil and mixed drift
 13-220 feet=to el.-190 feet=modified drift=mostly assorted
 sands and silts
 220-245 feet=to el.-215 feet=soft decayed schist
 245-355 feet=to el.-325 feet=Manhattan schist much broken
 — poor core recovery — worst material at about 225-240 feet
 and again near bottom. Formation evidently much shattered
 and considerably decayed
- g Hole no. 33 on 121st street, 300 feet east of Morningside Park
 East
 Surface elevation+31 feet
 Rock floor at depth of 195 feet=el.-164 feet

Material:

- 0-25 feet—soil and mixed drift
 25-195 feet=to el.-164 feet=drift, mostly modified drift=
 assorted sands and fine silts
 190-195 feet coarser material—pebbles
 195-200 feet=to el.-169 feet=Inwood limestone, coarser lime-
 stone of usual type
 200-237 feet=to el.-206 feet=Manhattan schist
 Ordinary type and in good condition [for interpretation *see*
 later comments]

Condition of the limestone schist contact. The finding of Inwood limestone above the Manhattan schist in hole no. 33 at 121st street east of Morningside and the fairly sound condition of both types raises the general question of the condition of contact zones as compared with fault zones.

There are three important facts to consider bearing on this case: (1) The contact zones are commonly weaker than either formation alone and (2) at this particular point an abnormal relationship is shown by the overturned strata (the limestone lying above), and (3) the fault zones are always weak and extensively decayed.

Because of the abnormal position of the limestone here, lying as it does overturned, a weaker more pervious rock upon a more substantial and less pervious one, it appears to be reasonable enough to find the limestone and schist fairly well preserved, under conditions where a vertical or a normal position would have encouraged decay because permitting a more ready circulation.

But there is a further conclusion that seems allowable, i. e. the fault or crush zones are more extensively decayed than the simple contact or transition zones. And contrariwise, where an especially extensive decay is encountered, it probably is to be associated with a crush zone due to fault movement rather than with any other structure.

A further inference seems allowable from the data of these holes. It is probable that these fault zones do not follow the contacts or bedding exactly but cut across at low angles, sometimes coinciding with the contact lines and sometimes falling wholly within the limestone or the schist.

Great depth of decay at south end of Morningside Park. The finding of approximately 150 feet of decayed rock in hole no. 16 and of nearly 200 feet of similar type in hole no. 36, all so rotten that the material came up as a mud, raises a very difficult question as to the conditions that make such extensive decay possible.

Hole no. 7 (113th st.) shows extreme decay to elevation -204 feet
Hole no. 16 (110th st.) shows similar condition to elevation -250 feet

Hole no. 36 (108th st.) shows similar condition to elevation -185 feet

These three holes showing similar condition of very deep decay are located almost exactly in line. Nothing on either side of this line is in so poor condition.

Consideration of these conditions can not fail to raise certain questions of interpretation.

1 It would appear that at least one of these borings (no. 7) is near the schist-limestone contact. May they all lie then in the weakened contact zone?

2 It is true that at least one core (also from no. 7) shows a badly broken condition. May they all lie in a fault zone?

3 There is no reasonable doubt but that the geologic structure at the south end of Morningside Park is that of a pitching anticline carrying the limestone beneath the schist in its southward extension.

May the excessive decay be due to this relation?

The evidence on these various possibilities is not complete enough to make a conclusion very reliable. But there are two or three factors that have a bearing and they unite pretty well in supporting one view.

These factors are: (a) the exact alinement of these three holes, (b) the crushed core of hole no. 7, (c) the overturned position of the formations 10 blocks farther north, (hole no. 33), together with the apparently normal position in hole no. 16.

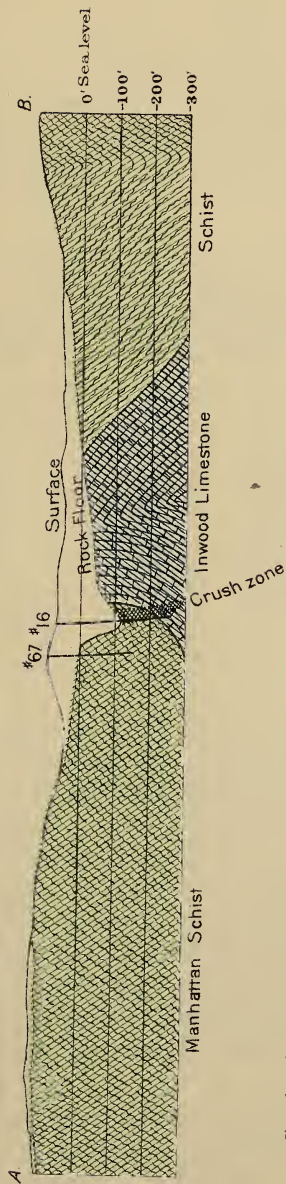
All of these points are consistent with the opinion that we have to do here with the crush zone of a fault, one that runs rather straight and one that follows not far from the contact of the schist and limestone at this point. And it is probable that the weakness follows the west margin or limb of the limestone anticline as it plunges beneath the schist. Such evidence as there is favors this view.

If that is true, then one may expect that the worst ground is not very wide, but that one probably can not go entirely around it. The best line would run south far enough to get above the limestone, and then cut across the weak zone nearly at right angles. It is certain that the ground improves southward.

Later borings are all confirmatory of the conclusion that the weakness is narrow and dies out rapidly southward as soon as the limestone passes well beneath the schist. No bad ground has yet been found on 106th street where the tunnel will probably be located.

4 The East river section

Preliminary studies of southern Manhattan and the East river led originally to the conclusion that the portion of the East river forming the great eastward bend from 32d street to Brooklyn bridge probably has a simpler geologic structure than those portions farther north or south. It was long known that the structure at Blackwells Island is very complex and involves all of the local formations in close folding and considerable faulting. But there seemed to the



Geologic cross section of the line A-B near 110th street, from Morningside Heights to Central Park, showing the anticlinal structure and location of the crush zone along which deep erosion and decay have been found

writer after studying all available data, good reason to believe that the river leaves this belt when it bends to the eastward and that it is in this part a displaced stream. In that case the East river could be flowing upon a floor of gneiss of a most substantial sort.

Explorations are now complete on a line that crosses the river from Clinton street, Manhattan, to Bridge street, Brooklyn. All borings have found good sound rock at moderate depth and all are comparatively shallow holes. Their positions and depths and rock types are tabulated below.

No. of boring	Distances in feet from Manhattan pier head line	Approximate interval in feet	Elevation of rock floor below mean sea level in feet	Type of rock	Formation
9	0	.....	-48	Granodiorite	Fordham
21	225	225	-65	"	"
53	350	125	-72	"	"
32	525	175	-71	"	"
50	695	170	-76	"	"
34	860	165	-74	"	"
41	960	100	-81	"	"
39	1070	110	-67	"	"
67	Brooklyn side near bulkhead	.....	-75	Banded gneiss	"

The rock floor is thus very uniform as to contour across the East river at this point. No water course yet explored about Manhattan island has shown so simple conditions including as it does sound rock and shallow channel. The rock varies a good deal but is pre-vaillingly a coarse grained granodiorite. In places it is very garnetiferous and at others is banded or micaceous, but all belong to the Fordham formation as a general formational unit.

Borings in the East river made by the Public Service Commission both above and below this point found an occasional deep hole with excessive decay to more than a hundred feet without securing sound core. At this crossing the deepest point in the channel to sound rock floor is 81 feet.

It is certain from these results and from others in adjacent ground that the East river does not occupy in this part of its course the original stream channel. It has been displaced (evicted) by glacial encroachment and has never been able to reoccupy the lost course. Therefore, instead of the river following a belt of lime-

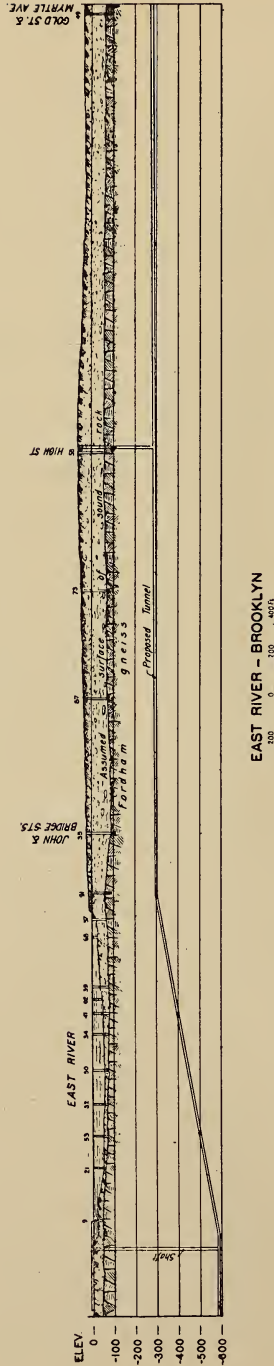


Fig. 40 Profile of surface and rock floor as indicated by borings from the foot of Clinton street, Manhattan, to Gold street and Myrtle avenue, Brooklyn. The rock floor is chiefly some variety of the Ravenswood granodiorite intrusive in the Fordham gneiss formation. It is one of the soundest rock types in New York city and the profile is more uniform than usual in any of the local formations. It is clear that the East river in this part of its course has no rock channel.

stone around this big bend as was formerly supposed, it follows no rock floor structure at all but is in this part of its course wholly superimposed. The original valley lies farther to the west cutting through the midst of the Lower East Side where the more complicated geologic structures again prevail.

Borings at intervals of 500 feet have now been made on the Brooklyn side of the East river to Gold street and Myrtle avenue. So far as developed there is no other formation than the Fordham and the associated granodiorite within the area covered. The rock floor is remarkably uniform at an elevation of from -70 to -90 feet. The accompanying section shows the relations of rock floor to present drift surface [fig. 40].

STRUCTURAL GEOLOGY OF THE LOWER EAST SIDE, DELANCEY AND CLINTON STREET SECTION

The proposed distributary conduit turns from the Bowery eastward on Delancey to Allen street, thence on Allen to Hester street, thence on Hester to Clinton street and follows south on Clinton to the East river. This so called Lower East Side section includes one of the most complicated geologic structures in New York city. The most complex portion extends from Christie street on the west side to Monroe street on the east. Between these two points all of the crystalline rock formations form a series of parallel beds that are folded together so closely that they stand practically on edge.

This general fact and the approximate location of the several beds have been proven for some time. But the more exact structure, with the depths to which the beds go before bending upward again, and the distances through each one are only approximately determined by the exploratory borings to date. The chief uncertainties arise from the fact that the beds are also faulted and the dips of the fault planes are not yet determined and the amount of displacement is unknown. The difficulty of forming a good estimate of the obscure points is greatly increased by the fact that no rock of any kind is to be seen at the surface. Judgment is based wholly on borings.

There are other important questions covering the zone, such as: (1) depth of serious decay, (2) location and width of these decay belts, (3) general physical condition of the rock at certain levels, (4) length of tunnel that will cut each formation, (5) best depth for safe construction.

The accompanying geologic cross section [pl. 38] embodies an opinion of the structural relations of the different formations. It is

offered as the writer's interpretation of borings to date, and its more direct use is as a working basis and guide in conducting explorations. The western half of the section may be accepted as more accurate in minor detail than the eastern.

To simplify the section it is drawn on a line crossing this zone more directly than the conduit as laid out, i. e. through holes 28 and 5 and the borings are projected along the strike of the formation to the section line. All the data therefore are used and the structure is not distorted, but the distances through each bed would be greater on the conduit line because it runs more diagonally across the formations.

Borings. The following tabulation of borings and interpretations upon them forms the basis of the present ideas of structure and quality of rock on the Lower East Side. The borings are given in order from west to east, and all points are neglected except those bearing upon geologic structure.

- 28 The Bowery and Delancey street
 Surface elevation 40.5 feet
 Rock floor -71 feet. Rock is Manhattan schist, and has been penetrated to -91 feet
- 78 Delancey street west of Christie
 Surface elevation 41.4 feet
 Rock floor -101.6 feet. Rock all typical *Manhattan schist* — at about 60°
- 224 and 301 North side of Delancey street west of Christie street
 Surface elevation 42 feet
 Rock floor at el. -99 feet
 Manhattan schist to el. -330 feet
 Inwood limestone to bottom at el. -395 feet
- 229 Northeast corner Delancey street and Christie street
 Surface elevation 43 feet
 Rock floor at el. -108 feet
 Manhattan schist with very poor core recovery to el. -260 feet
 Inwood limestone to bottom at el. -360 feet
- 84 Delancey street east of Christie
 Surface elevation 41.8 feet
 Rock floor -135 feet. All badly decayed schistose rock, of same type — no effervescence — red color — soft as cheese to -204 feet
- 227 is a reoccupation of this same hole 84
 Inwood limestone was found below el. -250 feet to the bottom below el. -300 feet

- 63 Delancey street west of Forsyth
Surface elevation 43.2 feet
Rock floor -141 feet. Inwood limestone at 80° — very low saving of core
- 72 Delancey street 121 feet east of Forsyth
Surface elevation 42.6 feet
Rock floor -122 feet. Very noncommittal rock, one piece very good Fordham and the rest not decidedly any special type
Classified as Fordham on this basis. Same behavior to bottom -109 feet
- 81 Delancey street and Eldridge
Surface elevation 41.7 feet
Rock floor -98 feet. Rock is typical Fordham gneiss — banded and very micaceous — to bottom -123 feet
- 225 North side of Delancey street east of Eldridge street
Surface elevation 40 feet
Rock floor at el. -74 feet
Fordham gneiss in good condition with interbedded limestone at bottom at el. -550 feet to bottom at el. -671 feet
- 25 Delancey street between Eldridge and Allen streets
Surface elevation 40.6 feet
Rock floor -68.3 feet. Banded Fordham gneiss — sound rock — dip about 45°
- 233 South side of Broome street east of Allen street
Surface elevation 42 feet
Rock floor at el. -96 feet
Fordham gneiss with good core recovery down to el. -200 feet
This hole is also known as 302 under a subsequent contract
- 85 Delancey street
Surface elevation 38.7 feet
Rock floor -82.3 feet. Banded Fordham gneiss — dip about 60° or less — bottom at -171 feet
- 223 Grand street east of Allen street
Surface elevation 41.2 feet
Rock floor at el. -123 feet
No core recovered in the first 140 feet
Inwood limestone with dip averaging about 45° from el. -303 feet to bottom at el. -710 feet
Splendid core recovery

- 208 Hester street east of Allen street
Rock floor at about -145 feet
Inwood limestone with structure at about 60 feet — 70°
Enters fairly sound rock and has continued to over 600 feet
with dip as low as 20°, toward the bottom
- 15 Delancey street near Ludlow
Surface elevation 35.7 feet
Rock floor -106 feet. Pegmatite and Inwood limestone, massive and bedding obscure
- 217 Southwest corner of Ludlow and Hester streets
Surface elevation 36 feet
Rock floor at el. -128 feet
Inwood limestone for more than a hundred feet succeeded by thin strips of gneiss and limestone interpreted as interbedded Fordham
- 222 Hester street west of Essex street
Surface elevation 36.6 feet
Rock floor at el. -130.4 feet
Fordham gneiss with interbedded limestone showing fair core recovery below el. -400 feet
Dip of rock structure about 60°
- 216 South side of Hester street between Essex and Suffolk streets
Surface elevation 33 feet
Rock floor at el. -167 feet
Interbedded limestone and Fordham gneiss with a dip of approximately 45° to el. -625 feet
Core recovery was variable
- 8 Norfolk and Grand streets
Surface elevation 35.8 feet
Rock floor -130 feet. Rock a close grained schistose limestone, Inwood, showing foliation at about 45°
- 231 South side of Hester street opposite Norfolk street
Surface elevation 32 feet
Rock floor at el. -103 feet
Decayed gneiss and no core recovery to el. -300 feet. This boring was continued as no. 303 under a subsequent contract and carried to el. -525 feet with only a small recovery of Fordham gneiss

- 218 South side of Hester street east of Norfolk street
Surface elevation 31 feet
Rock floor at el. -183 feet
No core recovered in upper 300 feet
Interbedded limestone in Fordham gneiss below el. -550 feet to bottom
- 77 Hester street near Suffolk [*see* 202]
- 202 Hester street west of Suffolk
Surface elevation 30.5 feet
Rock floor -99.5 feet. Rock all decayed to great depth
Manhattan schist to -470 feet
Fordham gneiss -470 feet to bottom at -577 feet
Believed to cross fault plane
- 213 Hester street 85 feet east of Suffolk street
Surface elevation 33.3 feet
Rock floor at el. -116.7 feet
The rock is Fordham gneiss of the black and white banded type, with dips varying from 30° to 80°. For a very short distance at el. -275 feet dips of 10°-15° were recorded
Core recovery very good
- 11 Hester and Clinton streets
Rock floor -204 feet. Badly disintegrated and no core to -279 feet. Unusual rock, identified as a mica schist of obscure structure (not typical). Some calcareous portions.
- At first this was thought to belong to the Manhattan formation, but it is probably a schistose and rather unusual facies of the Fordham series. This hole was subsequently reoccupied and deepened as no. 220 under another contract with the result that an interbedded series of gneisses and limestones was shown to a total final depth reaching el. -660 feet. Rock cores indicate dip of about 60°.
- 201 Clinton street between east Broadway and Henry street
Surface elevation -31.3 feet
Rock floor -133.7 feet
A schistose variety of Fordham gneiss with associated interbedded limestone
- 219 Northwest corner of Clinton and Madison streets
Surface elevation 26 feet
Rock floor at el. -214 feet
Fordham gneiss and interbedded limestone
Good core recovery below el. -400 feet

- 232 Southeast corner of Clinton and Madison streets
Surface elevation 25 feet
This hole was reoccupied as no. 304 and penetrated the rock floor at el. -353 feet
The boring has not progressed far enough to recover identifiable material for rock formation
- 211 East side of Clinton street south of Madison
Surface elevation 24
Rock floor elevation uncertain because of failure to recover core and the obscurity of the material washed up. Interbedded limestones and gneisses of Fordham series were recognized from el. -336 feet to el. -680 feet
- 51 and 207 Henry street between Clinton and Montgomery
Surface elevation 32.4 feet
Rock floor -214.6 feet. All badly decayed to great depth mostly believed to belong to limestone and underlain by interbedded Fordham gneiss at about -345 feet
- 221 Clinton street near Monroe street
Surface elevation 22 feet
Rock floor at el. -116 feet
Fordham gneiss mostly very sound, with some thin interbeds of limestone at about el. -500 feet
Dip of structure 45° to 80°
- 226 West side of Clinton street, north of South street
Surface elevation 10 feet
Rock floor at el. -37 feet
Fordham gneiss in very sound condition showing structure at 60° to 90°
- 305 Southwest corner of Clinton and South streets
Surface elevation 9 feet
Rock floor at el. -50 feet
Fordham gneiss with structure at 70°
- 4 Montgomery and Madison streets
Surface elevation -32.5 feet
Rock floor -65.5 feet. Fordham gneiss of granodiorite type
Two borings are of special interest and significance, and because of the rarity of such details being recorded they are given more fully below.

Each one is of great depth and indicates conditions decidedly different from the commonly accepted behavior for Manhattan Island.

Special interpretation of hole no. 202, on Hester st. near Suffolk st. This is one of the very deep borings, on the proposed distributary conduit, put down to investigate the character, condition, and structure of the rock through which the proposed tunnel would pass.

A summary of the data secured, together with an interpretation of conditions encountered follows:

1 *Boring record (summary)*

Elevation of surface = +30.5

a Glacial drift

0-123 feet. Soil and various types of glacial drift

b Residuary matter of local decay

130-150 red micaceous mud

c Disintegrating rock ledge too much decayed to furnish core

150-190 disintegration matter from pegmatite and associated ledge

190-214 quartz, hornblende, chlorite, mica, disintegration sand

d Decayed ledge rock capable of furnishing an occasional core

214-224 core—several pieces of coarse feldspathic, quartz mica rock

224-237 core—several pieces of core with much green mica

237-255 Cuttings and disintegration sands with much green mica

255-277 Pegmatite cuttings

277-305 Yellow clays and quartzose disintegration sands and cuttings

305-314 Core-pegmatite

314-388 Gray quartzose disintegration sands

402-447 Coarse quartz and mica disintegration sands and finer quartz-mica, hornblende-chlorite cuttings that do not look badly decayed. The rather surprising thing is their failure to core

447-463 Core—four pieces of schistose rock with white mica and garnet, nearly vertical, and three fragments of pegmatite

464-497 Cuttings only

- 497-512 Core — a quartz biotite, feldspar schistose rock that is rather easily disintegrated but does not show bad decay. Resembles the Fordham formation more than the Manhattan
- 512-531 Disintegration sand and cuttings containing abundant pearly mica
- 531-547 Core. Many fragments of coarse quartzose and micaceous limestone, interbedded type
- c* Ledge furnishing sound core
- 558-559 Core from quartz vein
- 573-588 Close textured quartz — feldspar — mica rock. Two pieces with foliation structure at about 60°
- 597-607 Typical banded Fordham gneiss with good structure, dip about 60°, common black and white or gray and white bands in good solid condition. Thin sections and microscopic examination of the rock indicate bottom perfectly crystalline, well interlocked, foliated rock with constituents in good sound condition

Summary of record and formation assignment

Feet

- 0-123 Soil and drift
- 130-150 Residuary matter of local decay
- 150-500 Ledge rock considerably decayed — micaceous schist passing into quartzose schist or gneiss mostly badly decayed, but occasionally giving core
- 500-531 Quartzose rock resembling the Fordham rather than the Manhattan
- 531-547 A quartzose limestone probably interbedded with the Fordham
- 558-607 Fordham gneiss, the lowermost part of which is very sound

Discussion of meaning of this hole

There were three rather puzzling features about the data of this hole at the time it was made: (1) The fact that Fordham gneiss was penetrated at a point so far to the west; (2) the finding of a small bed of quartzose limestone in the midst of other types; (3) the finding of both schistose rock closely resembling the Manhattan and typical Fordham gneiss in the same hole with so little space between.

As to these points, the first one needs little comment. That is, it seems to mean that much more of this Lower East Side ground be-

tween Madison on the east and the Bowery on the west belongs to the Fordham than at first supposed. This very much improves the outlook for safe and easy construction.

The second one, i. e. the finding of limestone at 531 feet is probably an interbedded limestone bed and not a part of the large Inwood formation.

The third point, i. e. the finding of schists and gneisses in the same hole introduced more difficulty of interpretation. This difficulty was considerably increased by the fact that the ledge is so badly decayed and so broken up in the drilling that no typical material for identification could be secured in the upper portion. There is no doubt as to the finding of Fordham in the lower portion. Later explorations support the conclusion that the whole belongs to the Fordham series.

When this boring was first made, the schistose portion was thought to be the Manhattan formation, and the limestone could then be Inwood. Subsequent exploratory work at other points has proven that the Fordham itself shows such schistose facies rather commonly where associated with the interbedded limestones. This is now the accepted interpretation for the whole eastern half of the Lower East Side belt covered in the present discussion.

There probably is some faulting. But whether the fault plane dips east or west and how much the total movement is has not yet been developed. This, however, is a more vital question than would at first appear, for if the fault dips east the ground to the west of it is probably all Fordham of good quality and will be easily explored, whereas if the fault plane dips to the west the whole west side for several blocks is much more uncertain. It is probable that the majority of the rock lying west of it will be of better quality than found in this hole.

Interpretation of hole no. 207 (old no. 51)

On Henry street midway between Clinton and Montgomery

Drill boring no. 207 has been put down to a depth of more than 655 feet (approximately -633). The material is of unusual quality and behavior and therefore seems to require special study with a view to reaching a correct interpretation. The most essential points of the drill record are given below.

1 *Explanatory record.*

- a Soil and glacial drift (surface to depth of 195 feet)
 Surface to 190 feet=sands, gravels, clays of unusual variety
 190-195 feet=reddish clay
- b Residuary matter — mostly decayed rock (195-247 feet).
 212-240 feet micaceous clay — judged to be residuary because
 of the abundance of mica and the scarcity of worn quartz
 grains and rarity of foreign particles
- c Decayed rock ledge preserving original structure
 representing interbedded limestone (247-377 feet)
 247 feet=decayed rock ledge with white blotches showing
 traces of structure
 256-330 feet=oxidized—mostly red and brown clays and sands
 from disintegration of decayed rock in place
 349-351 feet=gray micaceous clay
 251-377 feet=quartzose and micaceous disintegration sands
 and calcareous clays that effervesce in acid. Much pearly mica
- d Decayed rock ledge representing Fordham gneiss formation
 (377-489 feet)—no calcareous matter
 377-489 feet=quartz and pearly mica disintegration sand vary-
 ing from coarse to fine and mostly of very light buff color
- e Disintegration matter from a chloritized hornblendic gneiss of
 too little cohesion to withstand the grinding action of a drill
 of so small cross section (13/16 inch). (487-532 feet)
 487-532 feet=fine dark colored disintegration sand composed
 chiefly of quartz, chlorite and mica, the material is of same
 composition as the cores secured just below
- f Core from more substantial rock—a hornblendic gneiss sound
 enough in part to withstand the drilling process and save a
 small amount of core (532-655 feet)
 532-537 feet—9 pieces of a green chloritic foliated rock (14
 inches+) structure 70° - 80° —a close textured rock much
 oxidized and hydrated
 537-551 feet—8 small pieces and other fragments of same
 rock
 551-566 feet—17 pieces and several fragments same rock.
 All close texture and highly chloritic
 581-596 feet—2 small pieces (two very brown, hard pieces)
 are probably not natural — “drillite,” i. e. a peculiar product
 formed by the drill when it is run too dry and partly fuses
 fragments of rock and flakes of iron from the drill into a
 compact rocklike mass

611-631 feet — 14 pieces same chloritic foliated rock. Two pieces of "drillite"

One piece of fresh rock — a gray gneiss of rather worn texture

646-655.5 feet — 16 pieces of — a white and black and red blotched rock — a garnetiferous gneiss. The rock is not a common type but a similar variety is sometimes seen along the margins of the granodiorite intrusions and belongs to the Fordham gneiss series.

Rock is fairly sound and for the size of core the saving is good.
(3 feet)

2 *Deflection test.* A deflection test on this hole indicates that the drill has not departed more than 5° from the vertical.

3 *Behavior of drill.* It has been possible to drive the casing down after the drill without reducing the size and without enlarging the rock hole to a final depth of 625 feet.

About half of the water fed into the machine is lost — 10 gallons per minute being fed and 5½ gallons recovered.

The hole filled after each pull up as much as 100 feet with matter that either ran in from a crevice or was furnished by disintegration of the walls or was simply the settling of matters held in suspension during operation. These settleings or corings, as the case may be, were of large amount (100 feet ±) when the drill was cutting far below the casing and small in amount (5 feet) when the casing was driven down near to the bottom. This matter then increases as the hole is deepened again below the casing.

Cutting and progress are rapid and easy.

4 *Examination of the rock.* (a) Hornblendic gneiss. A microscopic examination of the green hornblendic gneiss shows that the rock is not badly crushed and that the different original grains are well interlocked. But the more easily affected mineral constituents are very generally decayed and have become especially modified on their surfaces where they interlock with other grains. The matter developed is mostly chlorite — a mineral that is very soft and one that in this case fails to furnish a very firm bond between the grains. A disrupting force exceeding the strength of this soft mineral therefore, such as drilling with a small bit or forcing the drill, causes the grains one by one to roll out or break apart and furnish the suspended matter that seems to be so abundant in this hole.

b The rock below 646 feet. This is a very unusual type of rock, the petrographic character of which need not be taken up here. It appears to be simply a contact variety, such as sometimes is devel-

oped along the margins of the granodiorite masses where they cut into the banded Fordham gneiss.

The essential feature of the rock is its fresh and sound character. This rock is not decayed.

5 *Interpretation*

a *Drift*

The glacial drift and soil cover the bed rock at this point for a depth of at least 195 feet.

b *Residuary soil*

Decayed residuary matter of local derivation is detected at 212 feet.

c *Bed rock*

The decayed matter still preserves the bed rock structures in a sample taken at 347 feet. From this point downward there is decayed rock ledge gradually becoming more substantial

d *Formations represented*

After bed rock is reached the first 100 feet is so altered that identification is not certain. At 350 feet, however, the calcareous nature of some of the material is observed, and on this ground largely it is believed that an interbedded limestone layer is penetrated down to about 377 feet.

From that point (377 feet) the material is very silicious and not at all calcareous and the core when obtained is distinctly gneissoid. This lower portion below (377 feet) is therefore judged to be typical Fordham gneiss.

The bottom material is sound but a very rare variety for this formation.

e *Character of contact*

Normally the interbedded limestone lies conformable to the structures and beds of Fordham gneiss. The structure in such pieces as show it indicated a dip of about 70-80°. Therefore the formation must stand very steep. But, so far as can be seen in the fragments secured, there is no direct evidence of a fault contact or anything abnormal. The extremely deep alteration of the rock is the chief unusual feature. It seems to require a better chance for water circulation than is natural in the undisturbed rock of either formation. For this reason, I am of the opinion that there has been movement in this zone that weakened the rock enough to encourage water circulation.

The formation dips west in normal manner at about 75 degrees.

f Condition of the rock

That the upper 100 feet of ledge is very rotten can not be denied, but it is certain that this lower portion of the hole is not in so bad condition as the low saving of core would lead one to think. The grains are affected by chloritic alteration in such manner that they can not resist much disrupting force. The small diameter of drill used subjects the whole core to enough strain to cause the gradual pulverization of the rock. This affects both the core that has been cut loose and the hole wall that is further subjected to the thrashing of the drill rods. A larger size core would make a very much more encouraging and fair showing.

There may be an occasional small seam so badly decayed that it is encouraged to run or cave under such treatment. But there is absolutely no evidence that slumping or caving is common or even likely on any considerable scale.

The material that partly fills up the hole when the drill is pulled up is believed to be in considerable part the settleings of suspended matter which during the agitation of drilling is distributed through the rising column of water. The reduction in volume (10 gallons being fed and only 5½ gallons being recovered) due to rock porosity is favorable to such behavior of the loosened material.

SUMMARY OF LOCAL GEOLOGY.

Formations. Only three formations are represented in the rock floor of this section. These are the regular crystallines characteristic of all southeastern New York.

1 Manhattan schist

2 Inwood limestone or dolomite, and

3 Fordham gneiss, including the Ravenswood granodiorite as a special intrusive member, and an unusually strong development of the interbedded limestones and associated schistose facies.

These formations have their usual relation—the Manhattan above and youngest, the Inwood intermediate, and the Fordham underneath and older. These simple relations, however, are much complicated by dynamic disturbances of more than usual violence so that the series is thrown into folds so close that the individual beds stand almost on edge. In addition lateral thrusts of that same time or later have broken the strata and faulted them in several places. This complicates the structures still more, and, since the

amount of displacement is in no case fully known, makes the structures in some minor details impossible to accurately interpret at this stage of the work.

Fault zones. As nearly as the material recovered can be classified and accredited to the above three formations it has been done. On this identification together with the location of points of greater decay the chief fault zones are drawn. The chief ones are judged to be thrust faults but it is possible that one is a normal fault. Such a combination is comparatively rare where the zones are so close together, but it seems to best explain the relations of beds as interpreted from identification of the present borings. It is not an unknown association though in this region. It probably indicates faulting in two different periods. This is consistent with the observation also that some of the fault breccia ground is not much decayed while others are badly affected. Probably the later movements have not allowed rehealing of the crevices and they are then the lines of chief circulation and alteration.

It is clear, upon examination of the section as now known,¹ that both the eastern and western belts of limestone are too thin and narrow to accommodate the whole Inwood limestone. The Inwood normally is a formation of about 750 feet or more in thickness. It is therefore certain that a part of it has been cut out by squeezing or faulting. If by faulting then there would be expected to be in each case somewhat greater decay than usual along the fault zones. The fact therefore that such decay zones are found along one margin of the limestone bed in each case leads to the conclusion that faulting is the true cause. In some cases thrust faulting would be required to produce the result and leave the beds standing in their present relations [*see pl. 38*].

INTERBEDDED LIMESTONES OLDER THAN THE INWOOD

The finding of limestone beds within the Fordham gneiss formation so persistently in the Lower East Side borings is one of the geologically interesting and rather surprising results of recent exploration. All of the borings in the Fordham gneiss area in this particular district except those near the East river have shown some limestone.

The individual beds vary greatly in thickness, ranging from only a few inches to many feet. Because of the steepness of the dip of the beds and the obscurity of this factor in many borings it is sel-

¹ October 1910.

dom possible to compute their thickness closely. It is probable that most of them are not over 5 to 10 feet thick, although rarely a thickness of 25 or 30 feet may be represented. It is certain also that a considerable number of separate beds are penetrated. All attempts to correlate the limestone cores from different adjacent holes have so far met with little success. No doubt some of those cut at great depth in one hole correspond to others cut higher in an adjacent hole. But the differences in thickness are notable even in the best cases, and it is evident that little dependence can be put upon uniformity of thickness as a factor in correlation. The foldings and crumplings, and shearing have probably affected the limestone members of the series more than any others. Limestones in comparatively thin beds are, under such conditions, especially liable to excessive thinning and thickening through recrystallization and rock flowage. It is not at all likely that any single bed at present preserves much uniformity of thickness. In some places they are pinched out entirely while in others they may attain a thickness much greater than the original. It is possible also that some of them are repeated by folding. Whether or not this is true in the Lower East Side section no one can tell. On the whole there is no direct evidence of repetition in this way. After making allowance for all possible duplication there is still a surprisingly large number of limestone interbeds represented — probably 10 — a larger number in succession than is known anywhere else in southeastern New York [*see pl. 38*].

In petrographic character these so called limestones are all essentially very coarsely crystalline dolomitic marbles or silicated dolomites of still more complex constitution. Occasionally a very pure carbonate rock is represented that corresponds in appearance very closely indeed to the best grades of the Inwood, but there is no doubt whatever of the true interbedded relation of these limestones. Their similarity of appearance to the Inwood in certain facies is so great that from the petrographic evidence alone one could not differentiate them. Their fixed relation however is unmistakable and they belong unquestionably to an entirely different geologic formation from the Inwood — a much older one, in fact the oldest known formation in southeastern New York — equivalent to the Grenville series of the Adirondacks and Canada. The silicated facies contains many of the common products of metamorphic processes. Recrystallization has produced micaceous minerals such as phlogopite and chlorite in abundance. Original and secondary quartz is

plentiful. Serpentine, tremolite, diopside, actinolite, occasionally chondrodite, and rarely metallic ores are found. In many cases the limestone passes by transition gradually into a more and more silicious facies until the rock is simply a silicious Fordham gneiss with quartz, mica and feldspar as the essential constituents. There is seldom a sharp break between the two types. Many pieces of apparently simple gneiss will show effervescence of a carbonate constituent with acid.

The silicious beds of the gneiss series proper immediately associated with the limestone layers are also more silicious or more micaceous than the average Fordham. They are essentially micaceous quartzites and mica schists and the rock generally lacks the strong black and white banding that characterizes the common or typical Fordham gneiss of other localities. It is this facies of the gneiss which most closely resembles certain facies of the Manhattan schist, and when the rock is much decayed or badly broken or is ground to pieces by the drill the confusion is still greater. The micaceous variety may readily be mistaken for Manhattan schist and the accompanying limestone may equally be mistaken for Inwood.

The occurrence of interbedded limestones of the Fordham series is probably more common than was formerly believed. They are not very often seen on the surface areas of gneiss. Possibly this is largely due to differential weathering and erosion which together tend to obscure those portions of outcrops where such beds may occur. But the type is well known. Mr W. W. Mather in his *Geology of the First Geological District* [1843] interpreted certain limestones in the Highlands as interbedded in their relation to the gneisses there. Later workers were inclined to disregard his views on this point and there was a marked tendency to place all limestone occurrences in one formation. Some of the geological maps have been made in this way. The writer, however, raised the issue again in an article published in 1907 under the title "Structural and Stratigraphic Features of the Basal Gneisses of The Highlands," a N. Y. State Museum Bulletin 107. It is certain that there are interbedded limestones with the gneisses in The Highlands. More recently, the writer has recognized similar occurrences in the typical Fordham gneisses of The Bronx, New York city. The vicinity of Jerome Park reservoir is the best locality in all southeastern New York to see this interbedded development. The best exposures are at the following places.

- 1 In the margin of Jerome Park reservoir at 205th street.

- 2 East side of Villa avenue north of Bedford Park boulevard.
- 3 East of the Concourse between 198th and 199th streets.
- 4 South side of 196th street both east and west of the Concourse.

One of these occurrences was known to the geologists of the United States Geological Survey [New York City, Folio No. 83] but it was regarded by them as an infold of the Inwood. An examination of all four occurrences will convince one that they are not infoldings. In at least two cases the structure accompanying the beds is actually anticlinal instead of synclinal.

These occurrences in the vicinity of Jerome Park reservoir are essentially the same as those disclosed by the borings of the Lower East Side. In spite of its thick drift cover — 50 to 200 feet — there are more limestone interbeds known there than in any other area of similar size in the region. It is entirely possible that a thorough exploration in certain other belts might reveal an equally elaborate development elsewhere.

The substantiation of interbedded limestones as a prominent element in certain facies of the gneiss series and their association with typical silicious gneiss layers with transitional relation emphasizes still more the strictly sedimentary origin of at least some portions of the Fordham series. Other observations lead to the conclusion that they are the oldest members of the series and that the igneous associates, of which there are many, are all younger intrusives.

One of these later intrusives is the Ravenswood granodiorite which cuts into the eastern margin of the Lower East Side, forms the floor of the present East river channel at the point of aqueduct crossing and continues as far as explorations have been carried into Brooklyn.

Structural detail of Lower East Side

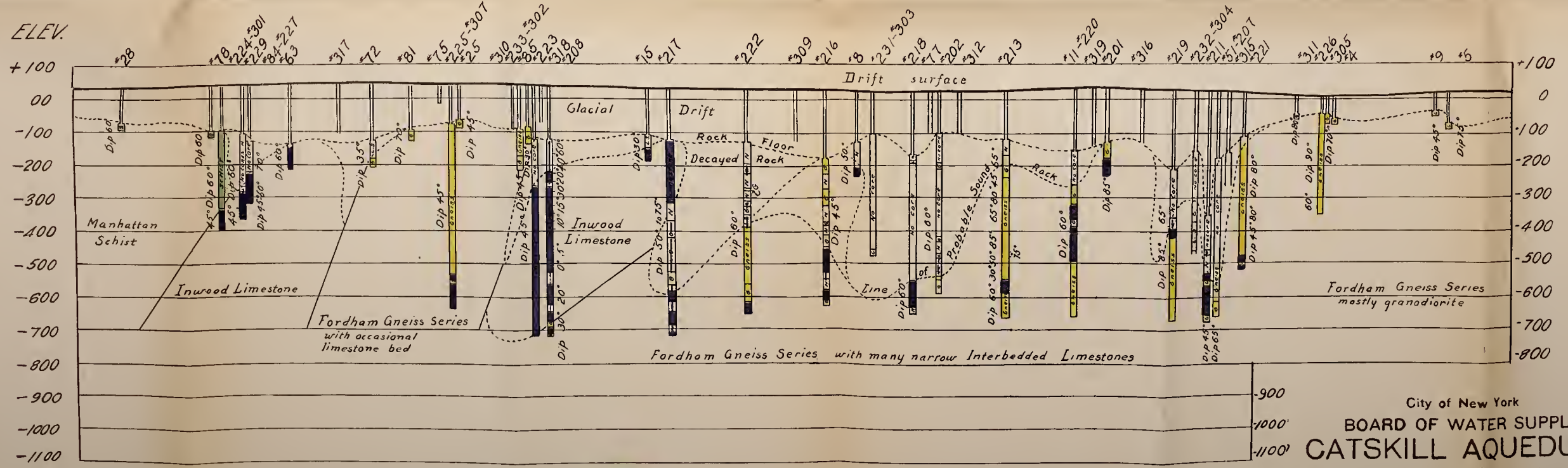
What the detailed structure of the Lower East Side is, it is impossible to say at the present stage of exploratory development. Its general features of structure are fairly clear. The Manhattan schist, which is the universal floor rock of the central and western parts of Manhattan island, extends only a short distance east of the Bowery. The Inwood limestone comes to the surface of the floor at Christie and Forsyth streets. An anticlinal ridge of gneiss comes up at Eldridge and Allen streets. Then a syncline of Inwood limestone is pinched into the next three or four blocks and from

this point eastward — from Norfolk street nearly to the East river — the Fordham gneiss with many interbeds of limestone forms the rock floor.

As much of this detail as it is now possible to classify has been included in the accompanying drawing, plate 38, in which special attention has been given to the interbedded limestone occurrences.

In view of the fact that a tunnel is finally to be constructed through this section which will cut the whole series of formations and structures at a depth probably between el. -600 and -700 feet, it is clear that much greater accuracy of geologic interpretation is soon to be attainable on many of the more obscure points. Because of this also it is not advisable to attempt a detailed structural cross section at the present time. It can very well await the more complete data to be gathered during construction of the tunnel.





The lower profile line is intended to mark the limit of rock decay as interpreted from borings. Each prominent depression probably indicates a crush zone belonging to a fault.

Schist - S -
 Limestone - L-LS -
 Gneiss - G -
 Recovery over 25% shown thus
 Recovery under " " "
 No Recovery " " "

NOTE -
 Borings are projected parallel to strike on line joining hole #28 and hole #5.
 Approximate bearing of strike is N 25° E

City of New York
 BOARD OF WATER SUPPLY
CATSKILL AQUEDUCT
 GEOLOGIC DETAIL OF LOWER EAST SIDE

200 0 200 400 Ft

OCTOBER 18, 1910

CHAPTER XX

THE GENERAL QUESTION OF POSTGLACIAL FAULTING

WITH ITS BEARING ON THE PERMANENCE OF ENGINEERING STRUCTURES.

Evidences of postglacial faulting and other recent movements have of late attracted a good deal of attention. The experience of San Francisco in the exceptionally disastrous earthquake and fire, traceable directly to earth movements of the nature of faulting which dislocated or injured the water conduits rendering them useless, is fresh in the minds of men everywhere who have public responsibilities of this kind. If displacements are occurring at the present time, or if any related movements are continuing, or if there is evidence of recent disturbances of this sort in this region, they have a decidedly important bearing upon the permanence of all engineering structures that cross them.

No undertaking is more vitally concerned with this question than the Catskill aqueduct. Although the principal factors to be taken into account have been considered in other connections [*see* "Faults" and "Folds," pt 1] a unified statement may encourage a more intelligent understanding of the bearing of these structures in southeastern New York on this specific question.

The region included in this discussion extends from the Catskill mountains to New York city. It will be convenient, for the purposes of this argument, to divide the whole area into three districts whose boundaries are determined by decided differences in complexity of geologic history. These lines necessarily follow closely the boundaries of greater stratigraphic unconformities. The youngest groups of strata have suffered only such changes as have accompanied movements of later geologic periods. But before they were formed the underlying groups of rocks were just as profoundly affected by earlier disturbances. In this region, at least, three such groups of large importance exist. The oldest or lowest has been affected by not only everything that has influenced the younger strata but by disturbances of a still earlier time which very much increase their complexity.

On this basis it is convenient to think of the three districts as follows:

A **Catskill district.** Including that portion of the region west and northwest of the Shawangunk mountains and marked by the

prevalence of Siluric and Devonian strata, i. e. all strata above the Hudson River slates. These strata have been affected by only one great mountain-making movement — that of the Appalachian folding, and minor disturbances of still later date.

B Hudson river district. This includes that portion of the region lying between the northern border of the Highlands and the Shawangunk mountains. It is marked by the prevalence of Cambrian and Ordovician strata, i. e. Hudson River slates, associated with Wappinger limestone and Poughquag quartzite as the chief bed rock. These strata have been affected not only by the Appalachian folding but also by a still earlier one — that of the Green mountains and the Taconic range. They were folded into mountain ranges and worn down in part again before the Siluric and Devonian strata of district *A* were in existence. Therefore as a structural problem this district (*B*) is approximately twice as complex as the other.

C Highlands district. This includes all of the region commonly known as the Highlands of the Hudson as well as the rest of the area south of the Highlands proper to New York city. Its rocks are the oldest — much the oldest. They had been folded into mountain structures and in part worn down before any of the others were accumulated. They have also suffered extensive igneous intrusion so that in places these igneous types prevail. And besides they have been metamorphosed far beyond the point of any other group. No other series of strata has been so profoundly affected. They form the lowest group. All things considered this district should be structurally three times as complicated at the first one (*A*), and adding the igneous and metamorphic complexities, it is probably more near the truth to consider this Highland district four or five times more complex.

All of the formations from the oldest to the Middle Devonian are involved. For the specific formations and their succession and relation the reader is referred to that discussion in part I [*see p. 29, et. seq.*].

Structural features

Except the most westerly part of the region, that occupied by the Upper Devonian strata, all formations are compressed into folds. Many of the smaller folds, especially those in the Catskill district, are still complete. The easy subdivision of strata possible in this district also simplifies the problem of detecting small changes of altitude. But for the most part the larger folds have been beveled off extensively by surface erosion so that only the truncated limbs

are now to be seen, and the strata therefore appear as narrow belts that dip steeply into the ground. This is more marked in the Hudson river district than in the Catskill, and is still more strikingly true of the Highlands.

There are evidently at least three different epochs of folding interrupting the processes of sedimentation and followed by periods of erosion before sedimentation was again resumed. These breaks constitute so called stratigraphic unconformities and occupy the relative positions indicated in the foregoing tabulated scheme [see pt 1].

In each epoch of folding the compressive forces accomplishing this work seem to have acted in a southeast-northwest direction causing successive series of folds with a northeast-southwest trend. The total amount of crustal shortening accompanying these movements is not known, but that it must be many miles is indicated by the fact that the strata of the older series of formations stand prevalently on edge. All stages between small amount of movement to very great displacement are represented.

Accompanying the folding in each epoch there has been a tendency to rupture and displacement of the "fault" type. There are multitudes of them varying from movements of too little amount to be regarded in a broad way to those of several hundred feet. Most of the larger and more persistent ones are strike faults and follow the main ridges or valleys, sometimes governing the location of escarpments or gorges. Dip faults crossing the formations also occur and doubtless have guided the adjustments of many tributary streams, and occasionally portions of the larger water courses. The thrust fault is most common. This is especially true of the larger ones and particularly those parallel to the trend of the other structural features.

The chief effects of these movements may be summarized as follows:

- 1 Formations are cut out of their normal order and nonadjacent ones are brought in contact.
- 2 Cliffs (escarpments) and sharp gulches are more common.
- 3 Crush zones (belts of brecciated material) are developed.
- 4 The crush zones give an additional control of stream adjustments.

All of these effects are common. Many of those faults dating back to the earlier epochs are obscure and not readily located. Many of the older weaknesses of this sort have been healed by recrystalli-

zation so that they are now as sound as any other portion of the rock. A good deal depends upon the type of rock and the conditions under which the movement took place. In some of the more open ones, circulating water has seriously affected the rock and in places there is extensive decay even in the harder crystalline formations.

Age of the faulting. The chief epochs of folding and faulting are those of the mountain-making movements — one Precambric, another Postordovicic, and still another Postcarbonic. All of these date very far back in geologic history, and since the last of these, nothing akin to them in importance has been felt in the region.

In Posttriasic times however there was small faulting south of the Highlands, that affected the areas of Triassic rocks of New Jersey and Connecticut.

Whether or not there continued to be slight movement along some of the older lines it is now impossible to say. It is at least clear that all of the great movements belong to very ancient time, and that the last period of geologic time as we know it for this region, has been one of comparative stability. The chief exception is evidently connected with the continental elevations and depressions of the glacial epoch.

Recent movements. The effects of glaciation make it possible to determine whether or not there has been further movement in postglacial time. Conditions are not everywhere favorable enough to detect minute changes, but where they do obtain, the evidence is capable of very definite interpretation. The essential features of these conditions are

1 A bed rock ledge that has been left well smoothed by glacial scouring.

2 Protection from postglacial destruction so that the original unevenness as left by the glacial smoothing can not be mistaken.

If on such a ledge, as now exposed, there are steplike offsets or minute escarpments that could not have remained had they been present during the ice action, then there must have been displacement to this extent, since the original smoothing took place.

A few such evidences have been found in New York and New England, and have been noted in geologic reports. W. W. Mather in his report on the First District of New York (1843) pages 156-57, was the first. The data as now known may be found in the last bulletin of Geologic Papers of the New York State Survey [*see* N. Y. State Mus. Bul. 107 (1907) p. 5-28]. The following para-

graphs are intended as a brief summary and comment on the facts as there given:

Localities where some postglacial displacement has been detected.

1 Copake, N. Y., on the eastern border of the State near the southwest corner of Massachusetts

2 Rensselaer, N. Y.

3 South Troy, N. Y.

4 Defreestville, N. Y. (near Troy)

5 Pumpkin Hollow, N. Y. (near Copake)

6 Kilburn Crag, N. H.

7 Port Kent, N. Y. (uncertain)

8 Attleboro, Mass.

In addition to these there is reference to similar occurrences at St John, N. B. and in the province of Quebec. All of the known localities lie a considerable distance beyond, north and northeast, of the Catskill aqueduct line.

Causes of displacement. In southern New York all of the cases of postglacial faulting yet discovered lie in the area of slates belonging to the Hudson River series. Whether the belt now occupied by this formation is therefore to be considered the most unstable zone, or whether there is some tendency to slight readjustment inherent in the slates themselves causing these movements, is not clear. It would seem consistent with known recent geologic history to connect these displacements with the general elevation and subsidences accompanying and following the glacial occupation. It is perfectly clear that the whole continental border in this region suffered considerable subsidence during glacial time. Also the terraces and deposits along the Hudson prove beyond question that during the ice retreat, at the very close of the glacial occupation, the land surface stood from 80 to 150 feet lower than now. Therefore an elevation of this amount has occurred in postglacial time, and probably, judging from the condition of the terraces themselves, took place soon after the glacial ice withdrew.

The stresses and inevitable warpings accompanying these mass movements seem to be sufficient to account for all displacements known to be of this age. There is nothing in them that necessarily promises a renewal of mountain folding. But it appears that the movements have almost all been of the thrust character and in this respect they differ not at all from the commoner type of the region.

Amount of displacement. The greatest throw noted on any single Postglacial fault in eastern New York is given by Woodworth as 6 inches, and he remarks that this is imperfectly shown. Usually the displacement is distributed over a zone in which several small faults occur instead of a single larger one. This may mean that the whole disturbance is essentially superficial.

At South Troy it is stated that a total displacement of 12 inches is thus distributed through a number of small faults within a distance of 30 feet.

At Rensselaer a total of 5 inches is given.

At Defreestville a total of 13 inches is indicated in a distance of 11.67 feet.

At Copake, at two different spots, a total of more than 7 inches was measured within a space of 12 feet. Woodworth thinks that the total displacement for the locality may exceed 2 feet.

At Pumpkin Hollow a total of 17 inches is estimated.

Conclusion. If such rates prevail over larger areas beneath the drift, it is clear that rather profound changes would be indicated. But thus far there is no indication of such continuity.

Likewise if it were certain that the movements are now in progress, it would be a matter of greater concern. But there is no direct evidence to prove it.

Estimates of the length of postglacial time differ greatly. The shortest ones worthy of consideration range from about 5000 to 10,000; the longest run above 100,000 years.

Some intermediate value is probably nearer the truth—say 25,000 years.

Adjusting the postglacial faulting problem then to these time estimates the summary of it all would be as follows: Somewhere within postglacial time, i. e. approximately 25,000 years, movements of strata have developed at a few places in eastern New York that appear as small faults with total throw in each locality varying from a few inches to perhaps as much as 2 feet. Whether the movement has been gradual and continuous or concentrated largely into some small portion of this time is not known. Whether the effects are extensive or, on the contrary, very local and superficial, is likewise unknown. But in any case there are no known instances of violent and large displacements, such as would be likely to cause great damage to sound structures, in this region in postglacial time.

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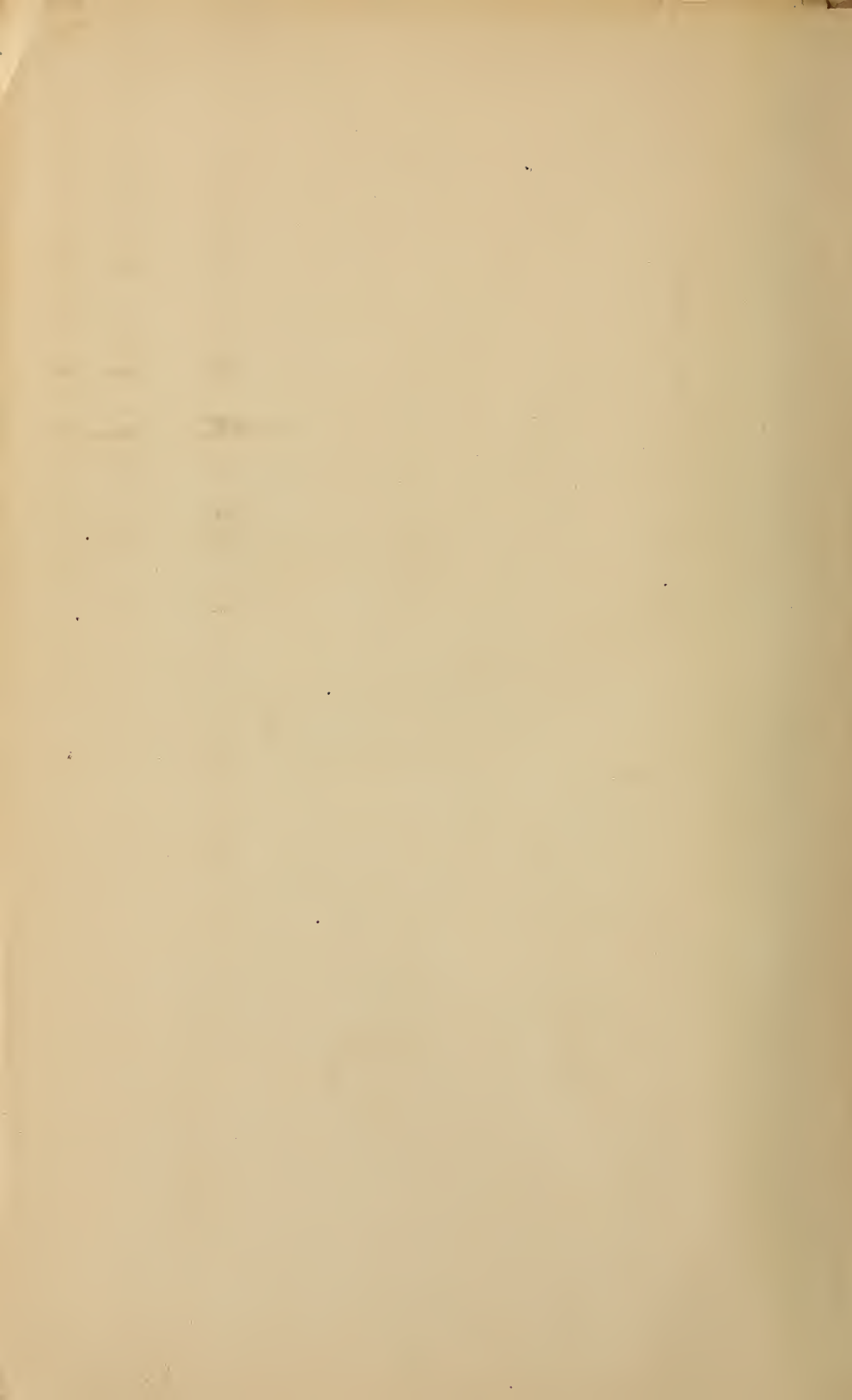
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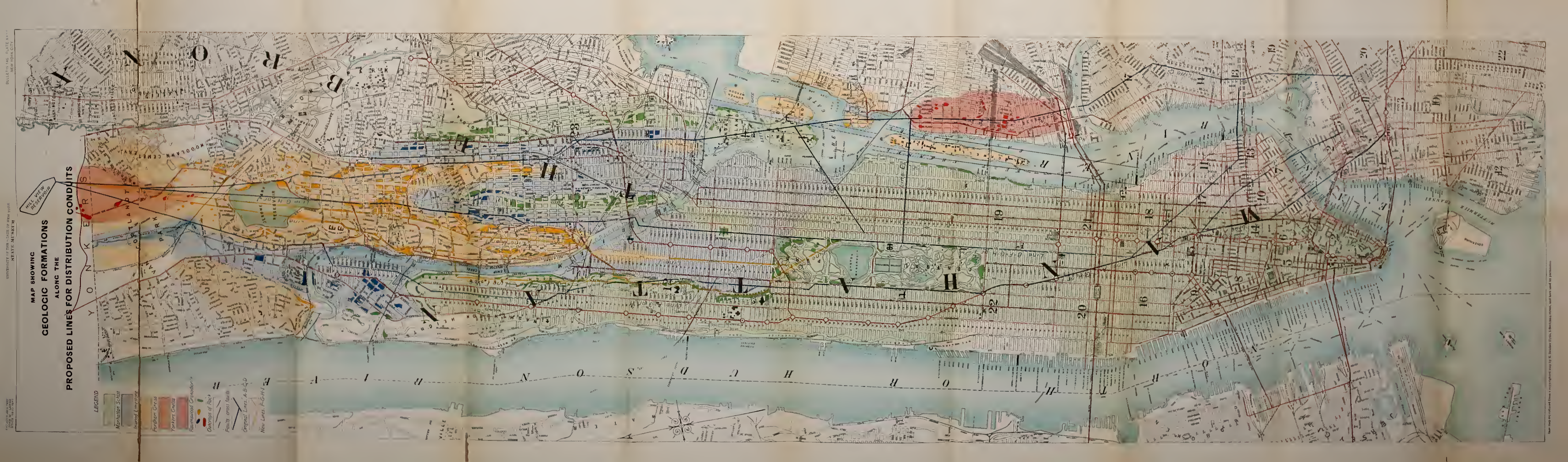
MUSEUM BULLETIN 145

Geologic maps of the Alexandria Bay, Cape Vincent, Clayton, Grindstone and Theresa
quadrangles

Hydrography of the Thousand Islands Region

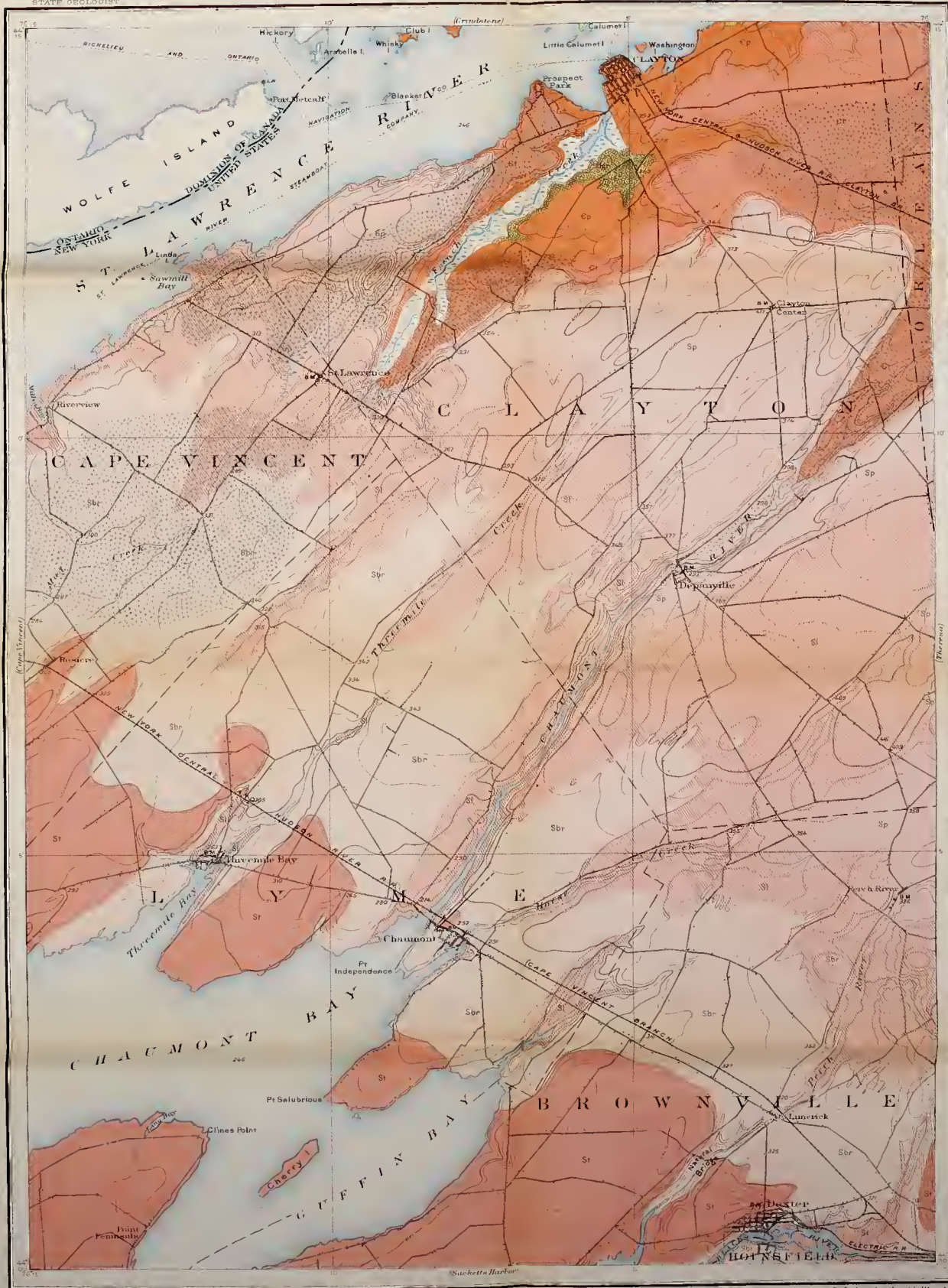
MUSEUM BULLETIN 146

Map of New York city showing geologic formations along the proposed lines for
distribution conduits



**MAP SHOWING
GEOLOGIC FORMATIONS
ALONG THE
PROPOSED LINES FOR DISTRIBUTION CONDUITS**

- LEGEND**
- Manhattan Schist
 - Freshwater Gravels
 - Freshwater Gravels
 - Parkers Gravels
 - Bluewood Gravels
 - Outcrops of Bed
 - Faulty cross walls
 - Original Lines, A-D, C-D
 - New Lines, F-G, H-I



LEGEND

Sedimentary Rocks

Pleistocene deposits covering other formations. (PLEISTOCENE)

Trenton limestone. Black and gray, mostly thin-bedded limestone. (LOWER SILURIC)

Waterson and Leray limestones. Massive, black limestone, cherty in the lower (Leray) member. (LOWER SILURIC)

Lowville limestone. Dove and blue dove limestone, both thick and thin-bedded. (LOWER SILURIC)

Pamela limestone. Black and blue limestone, alternating with gray and white earthy limestones. (UPPER CAMBRIC)

Theresa and Triles Hill formations. Sandy, calcareous dolomites, with some beds of coarse, weak sandstone. (UPPER CAMBRIC)

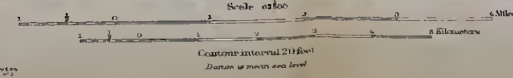
Potsdam sandstone. Red, white and buff sandstone with some coarse conglomerate. (UPPER CAMBRIC)

Igneous rocks holding inclusions of the Grenville rocks. (PRECAMBRIC)

Pictou granite of early Precambrian age, but younger than the Laurentian. (PRECAMBRIC)

Laurentian granite gneiss; exposed only in small outcrop by river east of Clayton. (PRECAMBRIC)

Fault Lines



Geology by H. P. Cushing (northeast half) and R. Ruedemann (southwest half), 1908



LEGEND

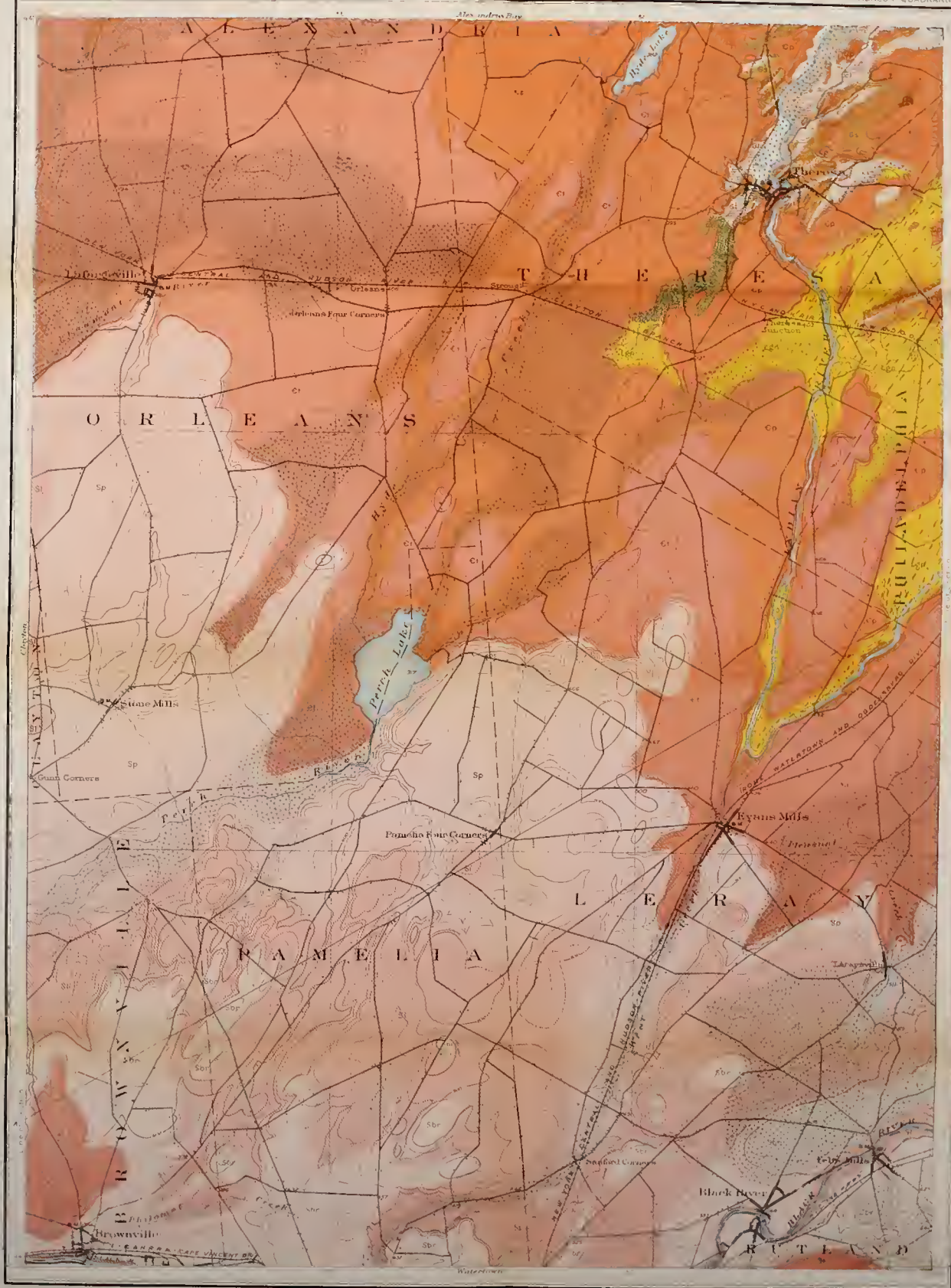
- Sr
Trenton limestone. Black and gray, mostly thin-bedded limestone.
- Sbr
Waterloo and Lerry limestone. Massive, black limestone, cherty in the lower (Lerry) member.
- St
Lowville limestone. Dove and blue dove limestone, both black and thin-bedded.

LOWER SILURIC

[Stony Island]

Scale 4:25,000
1 2 3 4 Miles
Contour Interval 20 Feet
Reference to Sea Level

Geology by R. Ruedemann
1908



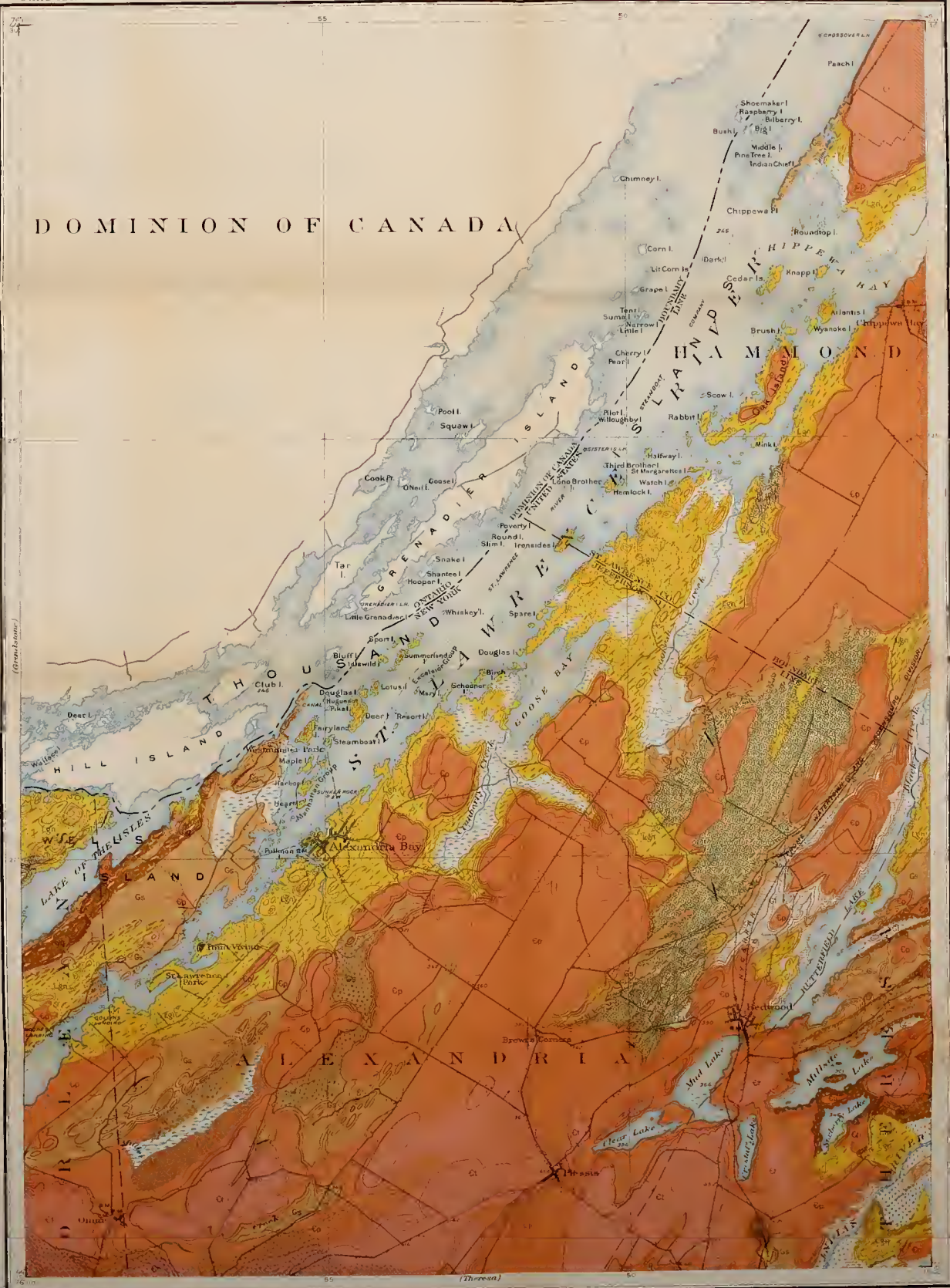
- LEGEND**
- Sedimentary Rocks**
- Pleistocene deposits. As overlain on other rocks whose boundaries are rounded, and mapping uncertain.
 - Trenton limestone. Gray and black, mostly thin-bedded limestone.
 - Leray and Watertown limestones. Massive, black limestone, shaly shaly.
 - Lowville limestone. Doss and blue limestone.
 - Pamela limestone. Gray and white, impure magnesian limestone, alternating with blue and yellow limestone.
 - Theresa and Leray Hill formations. Sandy, calcareous dolomites, alternating with coarse sandstone beds.
 - Potsdam sandstone. White, yellow gray, red and black sandstone, with local conglomerate.
 - Greenville limestone. White crystalline limestone with a local thin, low-crystalline phase.
 - Greenville quartzite. Coarse and fine, pure and impure, quartzite and quartz schists.
 - Greenville rocks other than limestone and quartzite. Various schists with thin limestone lenses.
 - Grenville rocks cut in place by dikes from the granite-gneiss.
 - Igneous Rocks.
 - Theresa granite. Early Precambrian but younger than the granite-gneiss.
 - Laurentian granite-gneiss including numerous inclusions of the Grenville rocks.
 - Laurentian granite-gneiss.
- LOWER SILURIAN**
- PALEOZOIC**
- UPPER CARBONIFEROUS**
- PRECAMBRIAN**

Scale 1:62,500

Geology by H. P. Cushing

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DOMINION OF CANADA



LEGEND

Sedimentary Rocks

- glacial deposits, converging boundaries. (Pleistocene)
- Theresa formation. Sandy, micaceous limestone, with beds of weak sandstone. (Upper Cambrian)
- Polish sandstone. Red, blue and buff sandstone with some coarse conglomerate. (Upper Cambrian)
- Grenville limestone. Generally coarse, white crystalline limestone. (Precambrian)
- Grenville quartzite. Coarse and fine, pure and impure quartzites and quartz schists. (Precambrian)
- Grenville schists. Comprising amphibolites and all other Grenville rocks except quartzites and limestones. (Precambrian)
- Grenville rocks, cut by numerous dikes from the igneous rocks. (Precambrian)

Igneous Rocks

- Dikes—dikes of late Precambrian age. (Precambrian)
- Various igneous rocks holding frequent inclusions of the Grenville rocks. (Precambrian)
- Alexandria syenite. Pleistocene age but younger than the Laurentian. (Precambrian)
- Laurentian granite gneiss. (Precambrian)

Geology By H. P. Cushing,
1902
Wells Island by C. H. Smyth, Jr.,
1908




HYDROGRAPHY OF THE THOUSAND ISLANDS REGION

H. L. FAIRCHILD
1909

LEGEND

 Proglacial divide between eastward and westward waters, now crossed by the diverted Black River.

 Present divide between St. Lawrence and Black Rivers, due to glacial diversion of the Black River.



DOMINION OF CANADA

LEGEND

Sedimentary Rocks

Glacial deposits overprint, where underlying rock is widely exposed.



Theresa formation. Sandy, blue gray, dolomite, weathering to rotten stone, with some interbedded weak sandstone.



Potsdam sandstone. Red, white and buff quartz sandstone, with some coarse conglomerate.



Grenville schists. Variable rocks, comprising all Grenville rocks, except quartzite and limestone.



Grenville quartzite. Coarse and fine, pure and impure quartzites and quartz schists.



Grenville rocks cut by numerous dikes of the igneous rocks.

Igneous Rocks



Diabase dikes.



Igneous rocks containing inclusions of the Grenville rocks.



Pieter granite. Coarse red granite with fine-grained phases, younger than the Laurentian.



Laurentian granite gneiss.

PLEISTOCENE

UPPER CAMBRIAN

PRECAMBRIAN

PRECAMBRIAN



Scale 1:50,000

Geology by H. F. Clifton and C. H. Smyth, 1908.

Contour interval 20 feet
 Datum as shown on local

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