New York State Museum Bulletin

Entered as second-class matter November 27, 1915 at the Post Office at Albany, N. Y., under the act of August 24, 1912. Acceptance for mailing at special rate of postage provided for in section 1103, act of October 3, 1917, authorized July 19, 1918.

Published monthly by The University of the State of New York

Nos. 225-226 ALBANY, N. Y. SEPTEMBER-OCTOBER 1919

The University of the State of New York

New York State Museum

JOHN M. CLARKE, Director

GEOLOGY OF THE WEST POINT QUADRANGLE, N. Y.

BY

CHARLES P. BERKEY AND MARION RICE

ALBANY

THE UNIVERSITY OF THE STATE OF NEW YORK

1921

M157r-Ja21-1300

The University of the State of New York

Department of Science, December 30, 1920

Dr John H. Finley

President of the University

SIR: — I communicate herewith for publication as a bulletin of the State Museum, a report on the *Geology of the West Point Quadrangle.*

Very respectfully
JOHN M. CLARKE
Director

Approved for publication

President of the University

Plate I

WEST POINT–COLD SPRING PANORAMA
Looking northwest through the northern gateway of the Highlands

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PREFACE

The West Point quadrangle is the only one in southeastern New York whose geology can not be appreciated at all without some knowledge of the most obscure phases of metamorphism, magmatic differentiation and the processes by which rocks may come to represent mixed types. Some of these fields are not well understood even by the most experienced workers and others furnish ground for much difference of opinion and interpretation. Many of the problems of origin, history and correlation are surrounded by obscurity and exceptional difficulty. Some of these are matters that workers in the average region do not encounter at all.

On this account the West Point report deals at much greater length than would otherwise be advisable with debatable and theoretical questions, such as the discussion of processes of origin, the methods of rock modification, the mechanics of structural confusion, and comparison of alternative hypotheses.

Metamorphic rocks, so extremely modified by a succession of different influences that one can not now determine what they were or how they are related, are common in this area, and igneous rocks so variable in character, so complex in internal structure and so confused in all their relations that one can not now determine how many separate units to recognize or what limits to give them, are equally charactertistic.

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Probably few districts can be found anywhere better illustrating the problem of petrogenesis of the mixed gneisses, and this one can not be described at all without undertaking such discussion.

We have, therefore, accepted the situation as it is and have devoted our best effort largely to an exposition of the origin and character and relation of such rocks belonging to the West Point district,— the now complex ancient sediments, the almost equally complex igneous members which are everywhere intimately related to them, and those still more complex and obscure rocks whose features in part resemble both the sediments and the igneous types and which are confidently believed to be actual mixtures. The bulletin therefore is only in part a description of the West Point quadrangle. To almost an equal degree it is a discussion of the principles involved in the origin of our oldest and most complex rocks.

Work was originally begun by the senior author of this paper on the Tarrytown quadrangle and a manuscript map has been in existence for many years. Before that work was finished, however, the investigations for the Catskill aqueduct began and new data of importance accumulated so rapidly that it was thought best to delay at least till full advantage could be secured from that study. Later it became apparent that the West Point area held more critical geological material bearing on the origin and correlation of the crystalline schists and gneisses than does the Tarrytown quadrangle. It was finally decided to accept this situation and issue the West Point bulletin first using it as a key discussion of the major genetic and structural problems of the region of crystalline rocks of southeastern New York.

It is not practicable to indicate individual responsibility for the different parts of this bulletin or for the departures from the usual treatment that it may contain.

The bulletin is a consistent attempt of a teacher and investigator of several years' experience in the district to cooperate with a junior associate whose insight into complex geologic problems and whose enthusiasm for field work has made it possible to finish a study begun long ago.

INTRODUCTORY DESCRIPTION

Location

The West Point quadrangle lies between 73° 45′ and 74° 00′ W. longitude and between 41° 15′ and 41° 30′ N. latitude. It is on the Hudson river in southeastern New York and includes a section of the "Highlands," a mountainous belt of country extending in a southwesterly direction from western New England across southeastern New York, northern New Jersey and into Pennsylvania. The Highlands belt is only about 15 miles broad where the Hudson river crosses it so that the West Point quadrangle includes the whole belt and also small triangular patches belonging to the lower country both on the north and the south sides. The total area is about 215 square miles and comprises parts of Westchester, Putnam, Dutchess, Orange and Rockland counties.

Geography

The Hudson river, deep enough for sea-going vessels, flows in a restricted gorgelike trench following an irregular course through the area from north to south near the western boundary of this quadrangle. There are no other navigable streams; only small mountain brooks or creeks enter the Hudson in this portion of its course.

The chief town is Peekskill (10,358 inhabitants) which lies on the east bank of the Hudson in the southern part of the quadrangle on the New York Central Railroad, about 40 miles from New York City. The best-known place is West Point, on the west bank of the Hudson, where the United States Military Academy is located. Other towns are Matteawan, Mahopac, Cold Spring, Garrison, Fort Montgomery and Highland Falls.

Three railroads run through the quadrangle; the main line of the New York Central, following close along the east bank of the Hudson; the West Shore, in similar manner along the west bank; and the Putnam division of the New York Central Railroad along the east side of the quadrangle up to Mahopac Mines.

The Interstate Park, which covers large areas just to the west, may be reached from Bear Mountain which is on the West Shore Railroad, or by river steamer.

Steamboat service is maintained by several lines between New York and Albany during the summer. Day boats and excursions stop at Bear Mountain and West Point. There is good ferry service from Garrison to West Point as long as the river is open, and inter-

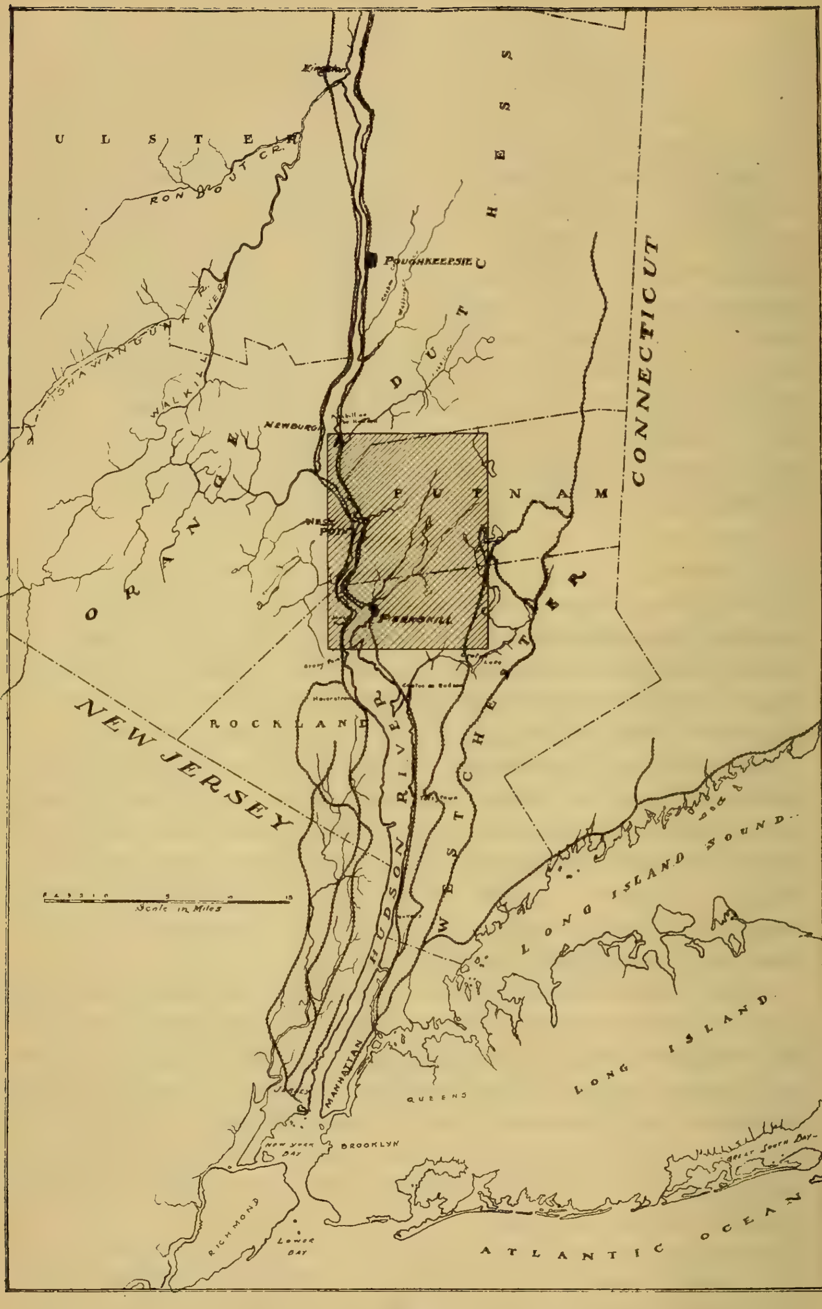

Plate 2

Location map showing the position and boundaries of the West Point quadrangle in relation to the chief geographic lines of the region mittent service from Peekskill to Bear Mountain and to Jones' Point.

Roads are numerous, except in the northeastern part of the area, and are fairly good. The state road is very good. It follows, for most of the way, the course of the old Albany post road through Montrose, Peekskill, Annsville, Nelson Corners, McKeel Corners through Clove Creek valley northward toward Poughkeepsie. Other equally good roads run from Peekskill to Pleasantside, Yorktown Heights, Mahopac Falls, and Tompkins Corners. The remainder are unimproved dirt roads, but many of them are fairly good. Some of those shown on the map were originally old wood roads and are now impassable for vehicles, and even in some cases are no longer traceable. On the other hand, new roads made since 1891, when the topographic sheet was surveyed, and even the new state roads, which are the best of all, are not shown on the map.

The region is a rugged one with much rocky and untillable ground, and, in many parts, very sparsely settled. In spite of its splendid transportation facilities both by rail and water, the West Point quadrangle contains few important industries. Peekskill, as the center of the trade for the best and most populous portion of the area, is a busy small city, and Cold Spring is the outlet of a small fertile valley, but no other place is much more than a station or a small village with very limited support. The proximity to New York City, however, together with the great natural beauty of the scenery, have attracted many people who have made costly improvements. The future of the district depends largely on the development of summer homes and country estates.

The inhabitants of the district outside of the special communities represented by West Point and Peekskill are mostly either small farmers, or traders in supplies and necessary commodities, or are residents with business interests quite outside the activities of the district. Few manufacturing establishments are located here, and none is wholly dependent upon the district itself either for supplies or service.

Physical Geography

The entire quadrangle, except about 3 square miles in the northwest corner and a small tract on the south margin, lies in the Highlands belt. This is a southwesterly continuation of the New England upland developed on the old resistant crystalline rocks which stand up several hundred feet above the softer Cambro-Ordovician sediments to the north. The northern boundary is an abrupt mountain wall 1600 feet high, forming, in the vicinity of the Hudson river gateway, Storm King mountain and Breakneck ridge. The southern boundary on the west side of the Hudson river is a similar wall, where the crystallines are faulted against the Paleozoics and Mesozoics. On the east side of the river, however, the Precambrian rocks decline more gently toward the south and continue to the limits of the quadrangle. The West Point quadrangle therefore bridges across the whole Highland belt from north to south, and includes a small amount of the characteristic physiographic and geologic features of the areas bordering the Highlands on both sides.

The country changes from low and gently rolling in the southeast quarter to rugged and mountainous in the west and northwest third, where it is characterized by narrow, steep ridges and straight, narrow valleys with a general northeast to southwest trend. This habit of relief, strikingly exhibited by such mountain ridges as Breakneck mountain or by such valleys as that of Peekskill Hollow creek, is so regular that it suggests at once some fundamental structural control in the geology. Here and there more independent masses rise as prominent mountains without any marked ridge habit. Such are Dunderberg and Anthony's Nose, the sentinels of the southern gateway. Storm King and Breakneck at the northern gateway, however, are parts of one strong ridge trenched by the Hudson river so that the two parts now appear as independent mountain ridges. The average surface elevation changes from 200 to 300 feet in the south to 1100 to 1200 feet in the north. The highest individual points are: Dunderberg, 1150 feet; Anthony's Nose, 900 feet; Crows Nest, 1396 feet; Storm King, 1340 feet; Bull Hill, 1425 feet; South Beacon, 1635 feet.

Across this rough, somewhat mountainous country the irregular Hudson river trench or gorge, one-half to one mile wide, extends from Storm King southward to Dunderberg, its walls rising sharply from the water's edge. Both north and south of the mountains the Hudson valley widens out to several miles.

An interesting feature of the Hudson gorge is the occurrence of small rocky islands, some of which are connected with the mainland by low swampy ground. The origin of the islands, which are rather unusual in a river of the age and character of the Hudson, will be discussed in a later chapter on the physiographic history of the area.

The most remarkable erosion feature of the area is the Hudson trench through the Highlands, for the Hudson river shows here the most extraordinary features of its whole course.

The fact that the Hudson is a drowned river affects its present appearance and behavior to a much greater degree than is usually appreciated. Although the Highlands area is 50 miles from the sea, the water level in the river is essentially sea level and is affected by the daily tides and is also contaminated by the mingling of waters from the sea. Superficially the gorge does not appear extraordinary, but the rock floor of the trench is very deep, though heavily filled with drift and silts and the present water level of this drowned river materially reduces the visible depth of the gorge and thus in part destroys its conspicuousness.

The exact depth of the gorge is not known at any point, but explorations that have been conducted in connection with the construction of the Catskill aqueduct have shown that it is several hundred feet deep and that at the northern gateway between Storm King and Breakneck mountain it extends more than 765 feet below the present water level. Boring operations at that point penetrated to this depth without encountering bedrock, and indicate that the gorge is filled with a great variety of drift materials and water-laid deposits. The fact that other tests of the rock floor showed solid rock at an estimated depth of 950 feet and the fact that the Catskill tunnel was actually constructed in solid rock at a depth of 1100 feet proves that the rock floor river bottom is somewhere between 765 and 950 feet. (For a fuller discussion of this question, see the chapter on Engineering geology under the item Storm King crossing.) No one knows whether or not the gorge is as deep as this throughout the Highlands, but this is probably its deepest and widest point. The gorge at water level is 3000 feet wide on the average.

There are three remarkably sharp turns or angles, at West Point, at Anthony's Nose and at Dunderberg. These changes in course undoubtedly are induced by the structure of the rock to which the river has become somewhat adjusted. But the river does not follow any single structure entirely across the Highlands belt, and thus it appears that these structures are incidental rather than primary controls in the original course of the river.

Terraces about 150 feet above sea level are very well marked within the Highlands belt at certain places, but it is a very striking thing indeed that there is almost no trace of terrace development at Storm King, Crows Nest, Dunderberg, Anthony's Nose or Bull Hill. In other words, the massive granite belts show absolutely no development of terraces whereas terraces are prominently developed on the complex gneisses. They are especially well developed along certain stretches on the east side where the land in places runs back almost level for half a mile to the foot of the bordering steep hills. This terrace development has given opportunity for establishment of such settlements as West Point, Cold Spring, Garrison and Highland Falls. It is not continuous enough, however, to be made use of by the transportation lines which on both sides of the river follow close to the water's edge, and which are constructed by cutting and tunnelling and sometimes even by running out on the glacial fill and alluvium of the river. In some places this drift and silt support has been rather unstable and has required considerable protection from stream erosion. If one pictures the rock gorge in its true cross-section without its filling it is very striking that the West Shore and the main line of the New York Central railroads are perched along the sides several hundred feet above the bottom, not even on the terraces, but sometimes following along the rock wall in narrow notches and tunnels and sometimes resting on the loose drift fill.

The tributaries to the Hudson are all very small streams. Those that enter the gorge are unimportant, both in size and number. North of the Highlands, Fishkill creek flows in from the east over the flat lands, and near the south margin, Peekskill Hollow and Annsville creeks empty together into the Hudson.

Some of the tributary valleys have the typical U-form characteristic of glacial erosion and some of the smaller ones are hanging. In the back country drainage is comparatively poor because of glacial deposits, and small lakes are common. Some advantage has been taken of these natural basins in the making of larger water storage reservoirs in water supply development.

Soil

The quadrangle as a whole is rocky and rugged with many bare rock stretches and a very stony, poor looking, or difficult working soil. This is true of great portions of the north and west sides of the area. It is not true, however, of the southeast portion nor of some of the principal creek valleys, such as Foundry brook or Peekskill creek, where there are very good farmlands. Occasional upland localities have good soil, but these are comparatively rare.

The soils, with few and insignificant exceptions, are of glacial origin and have the variety that characterizes drift soils and drift accumulations. The glacial ice which swept over this region came in general from the north, and, in part, across very long distances, carrying with it many kinds of foreign material which mixed with the materials that belong within the district. Since these local materials are derived chiefly from crystalline hard rocks, the most abundant constituents of the soil especially in its coarser portions are more or less decayed fragments of these rocks. The finer material has come from longer distances in surprisingly large amount and has mingled with coarser matter of local origin. In many places extensive accumulations of fine sands and sandy soils show large amounts of material that could have been derived only from the slates of the Hudson River valley. Occasional boulders of entirely foreign sort must have come from the Catskills, or in more rare cases, even from the Adirondacks.

As a result of such an origin the soils are of a strikingly mixed type, bouldery, gravelly, or sandy, with preponderance of crystalline material. In many of the valley bottoms and in small areas where irregular distribution of drift made swamps in former times, heavy silts and muck soils have been developed. But there is no simple law of their distribution; each case is dependent on local conditions, only a part of which is dependent upon the rock floor topography.

In some of the valleys the drift is very deep. The tendency of glaciation in this district was to subdue the relief that must have characterized the Preglacial highlands. Pinnacles of rock were undoubtedly worn down and carried away, and the deeper irregularities or depressions were subsequently filled or partially filled with drift. It thus happens that in some places the soil cover is very thick. In the southeast corner of the quadrangle, for example, the drift is so heavy that few outcrops of rock ledge can be seen, and a very critical structural relation belonging to that area is hopelessly obscured by the heavy drift.

The district does not show any particularly valuable or exceptional type of soil and in the nature of the case, no particular quality could be expected to cover a large area. This is a district, therefore, where it is not safe to assume that any piece of land carries good soil simply because it is surrounded by or adjacent to land which is known to be good. There is no residuary soil of economic consequence. A few remnants of residuary soil have been observed and one[1] of these cases in particular has been the cause of considerable attention in connection with the construction of the Catskill aqueduct.

[1] This is the north end of the Garrison tunnel; for a description of it, see chapter on Engineering geology.

Climate

The climate of this district is more severe than at New York City. Although only 50 miles inland it is not greatly affected by the influence of the sea. The winters are cold, temperatures of 30 degrees below zero having been recorded, whereas such a temperature has never been known at New York City. A difference of about 20 degrees between these two places is common. It is not, however, quite so cold on the average as the Catskills 50 miles farther to the northwest and not nearly so cold as the Adirondacks 150 miles farther north. In the summer, although the temperature is as high as on the coast, excessively humid atmosphere is seldom felt.

Rainfall amounts to approximately 48 inches a year and is heaviest in the spring and early summer. The average yearly rainfall is well enough distributed through the summer so that vegetation is kept green and farms seldom suffer seriously from lack of moisture.

Discovery and Colonial History

In 1609 Henry Hudson, an explorer of English birth sailing under the Dutch flag, entered the Hudson river and proceeded as far as Albany. The lower Hudson on the present site of New York City was the second permanently occupied spot within the borders of the United States. In 1613 Adrian Block built rude huts in which to spend the winter there. Hendrick Christiansen established a fort at Albany in 1614 and inaugurated commerce on the Hudson river, the three-hundredth year of which was celebrated 1914.

Settlement pushed up the river slowly because of difficulty and dangers but at least two attempts to establish settlements beyond the Highlands were made before 1655. In that year a strong outpost was permanently established at Kingston. From that time on the territory of the Highlands was more or less fully within the control of the white man, although the natural ruggedness of the country and its resistance to cultivation has kept parts of it even to this day almost as wild as it must have been at the time of its discovery.

Revolutionary History

The barrier of mountains known as the Hudson Highlands, traversed by the narrow gorge of the Hudson river for some 12 miles between Peekskill and Cornwall, separates the Westchester county area from the fertile farmland of Orange and Dutchess counties. This wild and inaccessible belt with its woods and precipitous cliffs played an important part in the Revolutionary War and in fact may have determined the political destiny of the American colonies.

General Washington, defeated in the battle of Long Island and driven from his strongholds in New York and the lower part of the river, removed his headquarters to Newburgh on the north side of the mountains. For over two years he remained behind the shelter of these hills, with just enough strength to man his positions and oppose the British advance, though constantly threatened by a persistent enemy and once almost betrayed by the traitor Burr.

In October 1777, while Washington was in the south, the Hudson pathway through the hills was captured and all the fortifications in the Highlands were destroyed by a British force under Sir Henry Clinton in a brilliantly executed attack. Landing on the east side of the river at Verplanck's Point, this able commander caused General Putnam, who was holding the Albany post road with his main force encamped at Continentalville, in the valley north of Peekskill, to withdraw most of his forces from the west to the east bank.

The British force then quickly crossed to the west side of the river and found its way to the west of Dunderberg by a rapid march through the Timp pass. The objective was the forts guarding the approach to West Point, which were well placed upon the terrace so strongly developed on the west side of the river.

Once upon the smooth bench above the river, the British took Fort Montgomery in spite of a stubborn defence by the small force of Continentals, who were aided by the deep and easily defended trench of Popolopen brook, and in a few days the forts were all destroyed, and this topographic stronghold was in British hands. But defeats in the north forced the abandonment of the areas, and Washington, perceiving the importance of retaining control of this natural fortification, rebuilt his forts and stretched chains across the river to prevent the passage of the hostile fleet. Thereafter, in spite of diminished resources in men and munitions, he successfully retained his positions until the end of the war.

This rough wild country was an effective barrier to land communication except on the river itself up to the time of railroad building. But the railroad and the river together soon became the best route of emigration to the great unsettled interior regions. Since that time commerce has followed the same line in such volume that New York City, as the principal port to benefit by the advantages of this natural route, has become the greatest trade center of the continent.

GENERAL GEOLOGY

Introductory and Historical

The variety of rock types in the Highlands has been recognized since the beginning of the study of geology in America. Amos Eaton in his Index to the Geology of the Northern States says in speaking of this district, "I believe every known variety of granite is found here." The writers are convinced that this was a fair approximation to the actual facts.

The first careful study of the region was made by W. W. Mather in 1843.[2] In spite of the short time allowed for the completion of the work, necessitating the covering on an average of 30 square miles a day, not only were the broad general features recognized and described but a remarkable amount of local detail was collected. When the different use of technical terms is allowed for, his statement of the causes underlying the complexity of the country is seen to indicate a remarkable insight into the more difficult and obscure phases of Precambrian metamorphic and igneous geology, and is on the whole strikingly similar to the most recent conceptions. He seems to have regarded the region as made up of sedimentary strata metamorphosed by intrusives of great penetrating power. He continually mentions "the granite laminated among the limestone strata" (p. 484), "the granite interstratified with the gneiss" (p. 525), "the greenstone which is intruded in sheets and irregular masses among the gneiss and other rocks in the same way as granite and syenite" (p. 532).

He noted the association of the hornblende gneisses with the magnetite veins, "the hornblendic rocks are constantly associated with the beds of magnetic oxide of iron which are so numerous in the Highlands" (p. 534), and understood the true igneous character of the veins, "They form masses in gneiss and hornblendic gneiss rocks, which by casual examination would be called beds, but after careful examination of the facts I think they may be called veins. . . . They lie parallel to the layers of rock, but by close examination it is found in many instances after continuing this parallelism for a certain distance, the ore crosses a stratum of rock, and then resumes its parallelism, then crosses obliquely another and so on. . . . In other places where a great bed of ore occurs at some depth, only a few small stripes of ore penetrate through the superincumbent mass to the surface, as if the rocks had been cracked

[2] Mather, W. W. Geology of New York. Part I, comprising the geology of the First Geological District, 1843.

asunder, and these small seams of ore had been forced up from the main mass below" (p. 559). "The phenomena of the mines in many places on this vein (the Phillips vein) induce the idea of igneous injection, connected with a powerful upheaving force. The feldspar is often pearly, wrinkled, and with bent laminae. The appearance of hyalite, a mineral usually associated with volcanic and trap rocks; the apparent injection in veins among the seams and crevices of the rock; the appearance of softening of the gneiss and bending of its layers like flowing slag, seem to point to an igneous origin of this vein" (p. 564).

Such statements show an extraordinary grasp of the processes which formed the Highland rocks, and it would be difficult even with the newer phraseology, after nearly 80 years of development of geologic science to describe the salient features better or to paint the minor structural peculiarities as well.

Mather's description of the larger structural features of the Highlands also is worthy of note.

"The Highlands in Rockland and Orange are a continuation of those of Putnam and Westchester counties, and are similar in general aspect, in the kinds of rocks, and in their mineral products. The rocks consist of gneiss, and hornblendic gneiss, syenite, granite, limestone, hornblende, serpentine, augite and trappean rocks. The strata dip to the southeast at angles from fifty to ninety degrees, but there are localities where the strike and dip are transverse to the general directions. The strata are intersected by seams transverse to the direction of the strata, and nearly perpendicular to the line of bearing, and at intervals of one hundred to ten thousand yards. Dislocations and vertical and lateral heaves have occurred along many of these lines of fracture. The outcropping edges of the strata are not parallel to the line of bearing, but like the ridges, slope gradually down to the northeast; while on the southwest, steep escarpments range along the lines of faults. Many of these faults are upon an enormous scale, and render the tracing of narrow beds of rock of economical value a matter of no small difficulty. There are no continuous ridges of mountains of more than a few miles in length, in consequence of the interruptions caused by dislocations and lateral heaves of masses of the strata. The hills of similar rocks succeed each other in echelon lines, which seem to have been caused by lateral heaves along the lines of fault. In consequence of this, neither the line of outcrop nor the line of bearing is parallel to the general direction of the Highlands, but ridge succeeds ridge, each of which runs out and diminishes in height until it disappears below the rocks which are generally considered of more recent origin" (p. 517).

Since Mather's time no very large amount of areal work on the Highlands has been published, although various investigators have worked in the region in connection with special problems.

James D. Dana in 1880 studied the limestones of Westchester county.[3] He states that the limestones are interbedded with the gneisses and that Westchester county owes many of its topographic features to its limestone belts which determine river valleys, marshes and lakes (p. 28).

In the West Point quadrangle he observed that the limestones in the southern part have an east-west trend which is abnormal in this region, and also that the two largest valleys in the Highlands proper, Conopus hollow and Peekskill hollow, are developed on limestone.

In 1896 The University of the State of New York published a map of the State which represents the Hihgland region differently from the map published with this bulletin. The chief discrepancy lies in their correlation of all the limestones as upper Silurian. The more recent work in the area indicates the presence of both Precambrian and Paleozoic limestones.

On the adjoining regions of New York, Pennsylvania, Massachusetts and Connecticut, various papers [5] have been published.

In the Raritan folio[6] a more fully matured and complete descriptions of the formational units recognized by the New Jersey Survey may be found. The same divisions are supported as in the earlier publication and thus the names Pochuck, Losee and Byram gneiss have become firmly established.

The authors of these New Jersey folios divide the Precambrian series into two main types, sedimentary and igneous. The sedimentary is now represented only by the limestone strata and by part

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[3] Dana, J. D., Limestone Belts of Westchester County, New York Amer. Jour. Sci. and Art. v. 20. 1880.

[4] Geological Map of the State of New York. F. J. H. Merrill.

[5] U. S. Geol. Survey Geologic Folio No. 161. Franklin Furnace Folio (1908). Spencer, A. C., Kummel, H. B., Wolff, J. E., Salisbury, R. D., Palache, Charles.

U. S. Geol. Survey Geologic Folio No. 162. The Philadelphia Folio. Bascom, F., Clark, H. B., Darton, N. H., Kummel, H. B., Salisbury, R. D., Miller, B. L., Knapp, C. N.

Geological Map of Connecticut. Conn. Geol. and Nat. Hist. Sur. Bul. 7 (1906). Gregory, H. E., and Robinson, H. H.

Geological Map of Massachusetts and Rhode Island, U. S. Geol. Survey Bul. 597 (1916). Emerson, B. K.

[6] Geologic Folio No. 191, U. S. Geol. Survey (1914). The Raritan Quadrangle. W. S. Bayley, R. D. Salisbury and H. B. Kummel.

of the Pochuck gneiss. The igneous is represented by three gneisses, the Pochuck, Byram and Losee, which are the dark-colored, medium, and light-colored types respectively. The Pochuck gneiss is hornblendic and probably corresponds to the hornblendic gneiss of the West Point sheet. It is believed to be partly igneous and partly sedimentary, but so much metamorphosed that the original character is indeterminable. Its relation to the other gneisses is unknown but probably it is older. The metamorphism may have been produced during the invasion of the granitoid gneisses. Those, known as the Losee and Byram, are more distinctly granitic and are interlayered with the Pochuck and with each other. Granite and pegmatite cut all the gneisses.

The following quotations suggest the chief structural conceptions: "The limestone and dark gneiss together seem to constitute a matrix holding the intrusive granitoid rocks in the form of relatively thin but extended plates." The gneisses are "so intricately mingled that detailed representation of their distribution is quite impracticable." "The varieties of gneiss are seldom found in large masses free from intermixture with other sorts, but the different facies or varieties occur in tabular masses which are interlayered both on a large and on a small scale." "That large amounts of preexisting rock material have been more or less completely dissolved or assimilated by the invading magmas is suspected, but can not be ascertained." "Throughout New Jersey evidence of crushing in the minerals of the gneisses is almost entirely wanting, and appearances strongly favor the belief that the gneissic foliation is original in the invading rocks of the Precambrian complex."

On the opposite side of this field in close enough proximity to demand equally careful consideration is the work of the Connecticut State Survey. The new state map includes representations of some of the same formations. The Connecticut geologists have rendered a good service in the discrimination of differences and in marking bounds and limits, but little attempt is made in the matter of correlation or genesis of the more obscure types.

In 1905 the senior author of this bulletin began work on the crystallines of southeastern New York for the New York Survey, starting in the Tarrytown quadrangle. The New York City area immediately south had been mapped and the description of its geology had been issued as a geologic folio[7] so that this seemed to be the most logical place to begin.

[7] Geologic Folio No. 83, U. S. Geol. Survey (1902). New York City and Vicinity. F. J. H. Merrills, N. H. Darton, A. Hollick, R. D. Salisbury, R. E. Dodge, Bailey Willis, H. A. Pressey.

Little opportunity to subdivide the basal gneiss member is presented in New York City, but through this piece of work the terms "Fordham gneiss" and "Yonkers gneiss" were established. Hudson schist, Stockbridge dolomite and Lowerre quartzite were used for younger members of the crystalline series. The first two terms have been used consistently by all workers since, but, because of the correlation difficulties introduced by those terms, the local terms "Manhattan schist" and "Inwood limestone" have generally been favored by students in this district in referring to the younger formations. The authors of folio 83 have correlated the crystalline limestone-schist series of New York City with the Hudson River-Wappinger series of the Upper Hudson valley. This whole matter of correlation, however, is considered by the present writers a very unsettled problem and a careful summary of the arguments on both sides is given in this bulletin on a later page. (See page 128.)

The work begun in 1905 for the New York Survey on the Tarrytown quadrangle was still incomplete when the exploratory investigations of the New York City board of water supply were inaugurated preliminary to the planning and construction of the Catskill aqueduct. The senior author of this bulletin was appointed geologist for this undertaking, and it thus became his duty to examine critically the whole region between the Catskills and New York City. Unusual opportunities were thus presented and it soon developed that considerable revision of the geology might be expected. Exploration and construction has taken more than 12 years and, in view of the fact that considerable change of conception concerning the geology of the more ancient portion of the region was developing, it was not thought desirable to issue so permanent a publication as a folio or a quadrangle bulletin until more stable hypotheses as to the nature and origin and grouping of these rocks were evolved.

In the meantime, however, several papers[8] of the nature of pre-

[8] Berkey, Charles P. Structural and Stratigraphic Features of the Basal Gneisses of the Highlands. N. Y. State Mus. Bul. 107, p. 361-78 (1907).

Berkey, Charles P. Geology of the New York City (Catskill) Aqueduct. N. Y. State Mus. Bul. 146 (1911).

Colony, R. J. High-grade Silica Materials for Glass, Refractories, and Abrasives. N. Y. State Mus. Bul. 203-204 (1917).

Fenner, Clarence N. The mode of formation of Certain Gneisses in the Highlands of New Jersey. Jour. Geol. 22:594-612. (94-202), (1914).

Fettke, Charles R. The Manhattan Schist of Southeastern New York State and Its Associated Igneous Rocks. Annals N. Y. Academy of Sciences, 23:193-260 (1913).

Gordon, C. E. Geology of the Poughkeepsie Quadrangle. N. Y. State Mus. Bul. 148 (1911).

Kemp, James F. Buried Channels Beneath the Hudson and Its Tributaries. Am. Jour. of Science. Ser. IV, 26:301-23 (1908).

liminary statements and discussions of particular formations or special problems have appeared. These were all inspired by and directed along the lines developing with the new studies just described. It is needless to say that such formational studies as those on the Cortlandt series by Rogers and the Manhattan schist by Fettke are the most detailed ever made on these formations and they are accepted as sound both in observation and interpretation. The remaining important formations deserve similar special treatment.

The bulletin on the Geology of the Catskill Aqueduct[9] contains some of the newer geologic developments from the investigations of the Catskill water supply project; but the purpose of that study did not yield to much elaboration of purely scientific discussion, such as detail of origin and structural habit and age or correlation of geologic formations.

As investigation and exploratory development progressed, it came finally to be appreciated that the West Point quadrangle contains the most suggestive and critical ground of the whole region and that it could be made a key study for southeastern New York. On this account the West Point quadrangle was selected as the one to receive earliest publication rather than the Tarrytown quadrangle, on which work was first begun and whose areal map has been in manuscript form for several years.

On the north side of the Highlands the Poughkeepsie quadrangle includes patches of the Highlands rocks and great areas of the Poughquag-Wappinger-Hudson River series of sediments. This district has been described and mapped by Clarence E. Gordon.[10] It is in some ways a critical district. Within its borders the Hudson river slates seem to transform gradually into highly metamorphosed schists in passing eastward until they can not be distinguished in appearance from the Manhattan schist of the south side. Mr Gor-

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Kemp, James F. Geological Problems Presented by the Catskill Aqueduct of the City of New York. Jour. of Canadian Min. Institute, 14:472–78 (1911).

Kemp, James F. The Storm King Crossing of the Hudson River by the New Catskill Aqueduct of New York City. Am. Jour. Sci. Ser. IV, 35:1–11 (1913).

Ridgway, Robert. The Hudson River Crossing of the Catskill Aqueduct. Jour. of the N. E. Water Works Assn., v. 25, no. 3 (1911).

Rogers, G. S. Geology of the Cortlandt Series and Its Emery Deposits. Annals of the N. Y. Academy of Sci., 21:11–86 (1911).

Stewart, Charles. The Magnetite Belts of Putnam County, N. Y. School of Mines Quar., 29:283–94 (1908).

[9] N. Y. State Mus. Bul. 146.

[10] The Geology of the Poughkeepsie Quadrangle. C. E. Gordon. N. Y. State Mus. Bul.

don's discussions of correlation problems therefore are of special interest in connection with the West Point studies.

On the south side, Charles R. Fettke[11] has made a special, very detailed study of the Manhattan schist. His contribution therefore supplements that of Mr Gordon.

The latest contribution[12] bearing directly on the geology of this district is that by R. J. Colony, which is confined to the Poughquag formation and its petrographic and chemical character.

Geologic Formations

The quadrangle is composed almost entirely of Precambrian gneisses, schists, and limestones (the Highlands gneiss, Inwood limestone, Manhattan schist) and their associated intrusives.

In the northwest corner a small area of the Hudson River series (Ordovician) appears and in the southwest is another small area of the Cambro-Ordovician quartzite, limestone and shale. The Manhattan schist is cut by the Peekskill granite and Cortlandt gabbro-diorite series of uncertain age which lie east of Peekskill.

The Highlands gneiss, which makes about 70 per cent of the total area, is considered to be the age equivalent of the Grenville gneiss and associated series of the Adirondacks and Canada, but here it is so penetrated and replaced by granites that its original character can be distinguished in few places. The chief belt which approaches the Grenville in character lies along the Hudson river where it shows as a series of thin calcareous, micaceous and quartzose beds cut by granites and pegmatites, and is much sheared and distorted by faulting. Almost all the remainder of the Highlands area is either granite or gneiss so granitized that it could readily be taken for a granite. The chief proof of the original sedimentary character of the country is found in the interbedded limestones, the largest of which underlies the valley of Sprout brook.

There has been extensive granitic intrusion and replacement throughout the area, and so intimate a mixture of granite and gneiss has been formed that it is usually difficult to determine the origin of any given outcrop. The simplest igneous rock of the region is the Storm King granite which forms Breakneck ridge and Bull hill on the east side of the Hudson, and practically all the mountainous area on the west side.

The general strike of the gneisses is northeast-southwest and the dip of the principal structure is steep to the southeast.

[11] The Manhattan Schist of Southeastern New York State and its Associated Igneous Rocks. Annals N. Y. Acad. Sci. 23:193–260 (1913).

[12] High Grade Silica Materials, N. Y. State Mus. Bul. 203, 204.

The Inwood limestone and Manhattan schist lie in the southeast part of the quadrangle. The limestone lies almost east-west and dips south. The schist overlies it conformably.

The Hudson River shales are faulted against the Storm King granite on the north. At the south a long fault runs northeast-southwest from Kent cliffs to Tompkins Cove. This is a continuation of the fault system which makes the Ramapo mountain escarpment to the southwest. An infaulted band of the Cambro-Ordovician sediments about one-half of a mile wide follows along this fault from Adams Corners on Peekskill Hollow creek to Peekskill, continuing across to the west side of the river and through Tompkins Cove southwestward.

The Cortlandt intrusives lie at the angle made by two faults or a fault and a strong flexure, the continuation of Peekskill Hollow fault and the Mahopac flexture. They are distinctly unmetamorphosed and show no signs of a complicated dynamic history.

Formations sufficiently prominent to be mapped. Several easily distinguished groups of formations are represented and in each group there are a certain number of readily distinguished members. The principal groups fall into a historical sequence, but there is no intention to discuss that relation at this point further than to present the general sequence from older to younger.

The great divisions or groups of formations are:

1 The ancient Precambrian gneisses, schists, granites and a variety of related rocks.

2 The Manhattan-Inwood-Lowerre series of crystalline schists and limestones which is of questionable age.

3 The Hudson River-Wappinger-Poughquag series of slate, limestone and quartzite of Cambro-Ordovician age.

4 The Cortlandt series of later intrusives.

The relative areas represented by these four groups on the accompanying geologic map bring out the fact that group 1, the ancient Precambrian gneiss-schist-granite series, occupies about two-thirds of the whole area and is the dominant group of this quadrangle.

The second group, crystalline schists and limestones of doubtful age, is found only in the southeast quarter of the quadrangle.

The fourth group, the Cortlandt series, occupies a compact area extending into the quadrangle from across the south line and covers about 20 square miles.

The third group, the Hudson River-Wappinger-Poughquag series, is found in a triangular patch in the northwest corner of the quadrangle and in one long downfaulted strip along Peekskill hollow and across the Hudson river to the south margin of the sheet. The amount of territory covered by the three minor groups is not very different one from the other. They are all small and comparatively insignificant in contrast to the dominant series represented by the ancient crystallines of Precambrian age.

The drift cover on the north margin and in the southeast quarter of the quadrangle obscures the boundaries of these groups so that mapping can not be done accurately, but over most of the quadrangle the major divisions are easily distinguished and are mapped with fair precision. In most cases, however, where the attempt is made to distinguish the minor subdivisions much greater difficulty is experienced. This difficulty is measurably increased by the fact that some of these smaller members are found only in those areas already referred to as being obscured by drift. The greatest uncertainty of this sort is in the southeast quarter, where certain critical structural relations must exist, but can not be seen because of the heavy cover of glacial deposits.

On other portions of the area, more elevated and rugged, representing the Highlands belt proper, outcrops are numerous and very extensive, and the difficulties emphasized above do not exist, but other greater ones appear. In this case the difficulty arises from the normal obscurity of the structural relations and the great variability of appearance and quality of the formations themselves. It is the sort of problem that always confronts one in attempting to draw lines of division in a series which seems to have all sorts of gradations and transitions and no sharp boundaries. The best that can be said in the matter of formational subdivision of this ancient series of gneisses and granites is this: Certain dominant types are recognized as fundamentally distinct and all the variations noted in them and between them are understandable as developments from these fundamental units under the history indicated for the region. (See statement of the petrogenesis of this series, page 29.)

There is very great petrographic variability in nearly all formations of the quadrangle. This is particularly true of the more ancient ones and less true of those representing slightly metamorphosed sediments. But all that have Precambrian history exhibit elaborate petrographic variations, some of which are extremely difficult to interpret. It is this great variability of the members themselves that has always made it difficult to do geological work in the

Highlands and that has appeared so hopelessly confused to the average observer. For example, it is no unusual thing to pass, within a short distance, from simple typical granite to typical banded gneisses and perfectly typical schists, and even to carbonate and lime silicate streaks representing former limy beds, without being able to draw a sharp line anywhere between the different portions. Such changes take place not occasionally, but repeatedly in a most confusing series of repetitions and variations. Then again a formation that seems to be a simple granite will in a short distance, without any apparent line of demarkation, pass into a rock of streaked structure which would, if seen alone, certainly be called a gneiss. If specimens were taken from two such nearby outcrops, it would scarcely be considered conceivable that the two could belong to the same formation and yet frequently in the field, where every inch of ground is exposed, there is no possible line of separation between them.

It thus happens that one becomes accustomed to including great ranges of quality and structural habit and mineral make-up within the bounds of a single field unit. If one were to attempt mapping on any other basis than this in the Highlands of New York, it could not be done on any scale much smaller than the ground itself, because some of these variations take place within distances of inches instead of feet or rods. And in those formations which have the most complicated history, differences in quality occur by the thousands in every conceivable method of arrangement, distribution and repetition.

It is necessary, therefore, to develop some method of generalization as the only practical measure, and the best basis for this is judged to be the origin and history. Units which have a definite origin or an understandable sequence of development of variations both within their own boundaries and upon their neighbors are considered objects of special significance. All petrographic variations are referred to one or another of these units. It is readily appreciated that generalization of this sort leaves much to be desired in the detail mapping and it is not assumed that mistakes have been wholly avoided; but it is the belief of the authors of this bulletin that a large part of the complexities of the geology of the Highlands may be made quite understandable on this basis. It gives a better interpretation of the area than could be derived from the most elaborate undertaking that tended to emphasize individual differences rather than the larger and more fundamental similarities.

Almost every variety of igneous or metamorphic rock that could be obtained by the differentiation of granite magmas and their attack on country rock is to be found here. And there have been several magmatic invasions, each making its own particular addition to the existing confusion. The more ancient gneisses, schists and limestones, already complex and obscure, are made even more so by contact influence and by magmatic and mineralizer impregnation of most elaborate character. This latter has served to mix, in hopeless confusion, constituents of original sedimentary with constituents of later igneous origin into a rock that is neither the one nor the other, but which can be understood as essentially an impregnation gneiss. There are also the banded types which are, in part at least, lit-par-lit injection of simple igneous matters along the weaknesses of the invaded rocks, all of which had been previously metamorphosed and may already have been impregnated. Successive attacks of this sort are not rare and a particular outcrop may contain representatives of practically all the igneous members of the Precambrian series.

Under these circumstances, quartzites may not be distinguishable from gneisses nor determinable as to igneous or sedimentary origin; and schists may be made from either recrystallized sediments or sheared igneous rocks. Limestones may be so changed by subtractions, additions and reorganizations of their constituent minerals as to be scarcely distinguishable as limestones at all.

It would be a mistake to assume that all the formations are so confused or that they all show such indeterminate penetrations and gradations. It is somewhat less characteristic of the Storm King granite than of the other Precambrian granites, but even this is, in some places, quite confused. The Grenville also, especially those beds in which limestones are prominent, seems to be readily distinguished. But one needs little experience to become convinced that even this simplicity is more apparent than real, for it is frequently impossible 10 or 15 feet away to determine whether one is dealing with an old sediment or an igneous rock. As far as appearances and structure are concerned, it might be either.

The chief types of rocks. It thus happens that one may list an exceedingly large number of rock species from these members of the Highlands series — enough to stock a museum of acid igneous rocks of intrusive and plutonic types, and the whole gamut of metamorphic rocks. The most abundant types, however, are the following:

Granites of many varieties, chiefly biotite or hornblende or pyroxene granite, and soda granites.

Pegmatite of great variety representing every extreme from pure quartz pegmatite on one side to magnetite ore on the other.

Dioritic rocks, both massive and gneissoid.

Basic igneous rocks (not very abundant in the Precambrian).

Dunite and gabbro and pyroxenite and hornblendite are representd.

Granite gneiss and gneissoid granite with indeterminate gradations.

Mica and quartz and hornblende schists.

Crystalline and silicated limestones.

Banded injection gneisses and impregnated gneiss of confused relation.

The chief geological problems are these two: first, to single out the principal fundamental units and map their general distribution; second, to determine the relation of these units to one another and the origin of their petrographic variability.

The structure of the region trends northeast and southwest Most of the formations fall into this structural trend in their own distribution. The principal control seems to be the original rock structure of the region itself, that of the Grenville. Even the folding and faulting of later time conforms to the same orientation. Such deviation as there is, arises chiefly from two causes, namely, (1) portions of igneous intrusions which have not developed a gneissoid habit often do not maintain the simplicity of the general structural trend; (2) some faults of later date cut across this general structure. Illustrations of the former cause of irregularity are such masses as Dunderberg mountain and Bull hill, and representatives of the later faulting are the Mahopac flexure and minor faults.

In some places the original northeast trend of the structure has been so disturbed by large intrusions that it is now almost perpendicular to the normal direction. This may be seen at Fort Montgomery, where the principal structure for a short distance trends northwest and southeast instead of northeast and southwest.

Method of mapping. On account of the obscurity of formational boundaries the difficulty of mapping can not be fully overcome. It is impossible to draw sharp lines of demarkation between certain formations. A method which more nearly represents the actual conditions of affairs would be to map distinct formations sharply where they are typically and clearly developed and allow them to overlap in intermediate or transitional zones, so that the colors are mingled in that portion where it is believed the actual rock materials are mixed. Even this method has disadvantages because of the difficulty of determining how much is due to mixture and how much is due to original individual variation, but it will lead to much less error and confusion of interpretation than to draw sharp lines of separation. This method, therefore, has been adopted as suitable to the purpose of this particular study and it is to be understood that where the colors are single or simple, it is the authors' judgment that the rocks are fairly distinct and distinguishable, but that where the colors overlap, the rocks are intermediate and probably mixed.

Individual formations mapped. On the basis explained above, the following formations have been determined as mappable.

A *Oldest metamorphics*

1 The Grenville series of metamorphis sediments (the oldest formation).

B *The older great igneous members*

2 An old injection or impregnation type of *Diorite gneiss* of uncertain relation to the other types except that it is intimately associated with the Grenville and is judged to be the oldest intrusive. This may be referred to as the *Peekskill diorite gneiss* or the *Pochuck gneiss.*

3 The *Canada Hill granite* and gneissoid granite with a multitude of variations.

4 The *Reservoir granite* and gneissoid granite, a xenolithic granite with many variations.

5 *The Storm King granite* and gneissoid granite with its injection borders.

C *Crystallines of doubtful relation and age*

6 *Lowerre quartzite,* not occurring in this district in large enough development to map. (Apparently conformable with the Grenville structure)

7 *Inwood limestone.* A crystalline limestone. The same rock that forms the limestone valleys of southeast New York, south of the Highlands to New York City.

8 *Manhattan schist.* A mica-schist, undoubtedly to be correlated with the extensive development of mica-schist overlying the Inwood limestone of the district south of the Highlands.

D *The Cambro-Ordovician series*

9 *Poughquag quartzite.* (Clearly unconformable on the Highland gneisses)

10 *Wappinger limestone.* (Conformable to the Poughquag)

11 *Hudson River slates and phyllites.* (Conformable above the Wappinger)

E Later intrusives belonging to the *Cortlandt series*

12 *Norites and dioritic rocks* of the principal Cortlandt area.

13 *Peekskill granite* and Mohegan granite (of Cortlandt series age).

PETROGRAPHIC GEOLOGY — ROCK FORMATIONS

This discussion is concerned chiefly with the following three items: (1) petrogenesis, (2) products of the geologic processes represented by groups of larger petrographic significance, (3) mappable formations and their petrography.

Petrogenesis

It has already been indicated that a confusion of types is characteristic of the Highlands district. The whole range of rock types capable of being developed from original complex sediments and associated igneous intrusives with both an older and subsequent dynamic history is shown here. And the complexity was not developed to its extreme in any one cycle. The history is bound up with successive igneous invasions, some of them very acid and others very basic so that an extreme range of composition is possible.

Dominant types. The task of resolving this confusion into a group of dominant types at first looks hopeless. But a critical inspection with a microscope reveals the fact that there is, in most cases, a recurrence of a peculiar habit or a critical character which, when one has the clue, is recognizable. This suggests that there are certain traceable relations which have a broad application in the matter of relation and identity of formations. This is readily recognized in the simpler Hudson River-Wappinger-Poughquag series of Cambro-Ordovician age. It is less easily followed and one's identifications become less certain in those formations of more complicated history, such as the Manhattan-Inwood-Lowerre series. The difficulty is so pronounced, in this case, that it is still a question what the true age of these members may be.

The difficulty of working with the Grenville is still greater because of the excessive modification that this formation has suffered. The limestone is the only member of the Grenville that maintains even moderately well some decisive evidence of its former make-up, perhaps because it is less susceptible to impregnation by igneous matters. At any rate at many places the limestone can be readily found, but the limits and exact nature of the other members are very uncertain indeed.

The igneous representatives are the most troublesome of all, not because of the difficulty in distinguishing between the members, but because, if one is interested in the genesis of their variations, it is necessary to consider so many possibilities of origin. Because of the obscurity of some of these conceptions, it is thought best to discuss this matter at some length before the individual formations are described.

Causes of variation in the crystalline rocks. The chief causes of variation may be listed as follows:

1 *Original differences* of composition in sediments.

2 *Dynamic Metamorphism* with recrystallization and deformation.

3 *Original magmatic differences* of the invading igneous magmas.

4 *Magmatic differentiation* within these igneous masses.

5 *Magmatic movement* with development of gneissoid habit.

6 *Syntexis* or magmatic absorption.

7 *Igneous injection* in its many forms of lit-par-lit banding, pegmatitic bunches, veins and dikes.

8 *Igneous impregnation* penetrating the grain of the original rock by extremely fluid and vigorous igneous matters, resulting finally in a mixed product which is in part original and in part introduced materials. These two causes (7 and 8) together give every possible gradation from one to the other and from both to the original invaded rock on the one side and to the invading igneous rock on the other.

9 *Contact effects* produced by igneous rocks on older rocks of all kinds.

10 *Deformation* which has resulted in the usual shearing, granulation, crumpling, recrystallization and schistosity.

These are the usual causes of variation in ancient rocks of complex history, but it seldom happens that all of them are so extensively developed and displayed so magnificently as in the Highlands. After one has studied the region and become convinced of the major features of its geology, the formations, with all their apparent confusion, do not appear a hopeless mess, but show clearly the effects of a most interesting series of processes, an understanding of which adds immeasurably to their interest. Instead of being a confused jumble, they constitute one of the best exhibits of deep-seated, vigorous transformation processes to be found within easy reach of large centers of population within the borders of the United States.

A walk across the West Point quadrangle with an understanding of the geological principles represented in its great variety of rock structure and composition is a better exhibit of structural and dynamic geology than a whole museum of specimens. Some of the principles represented, however, are so seldom encountered that it seems to be advisable to discuss at greater length the different processes involved in the petrogenesis.

Original differences of composition of sediments. This is clearly a possible cause of variation. The chief differences in the Grenville metamorphics doubtless depend upon this point. All the variety in the simpler metamorphosed sediments and much of it in the more complex ones is directly related to the variety of the original sediment with which the whole history began. Certain beds of particular composition have maintained their identity fairly well, others have recrystallized so as to be indistinguishable from similar rocks of very different origin, and still others have yielded to igneous attack to such extent as to have lost most of their original character, even their composition. Doubtless there were originally some thousands of feet of shales, sandstones and limestones in many repetitions and variations of quality. It is these rocks that have imposed their composition and structural influence on all subsequent products.

Metamorphism. There is hardly a formation in the region that does not show at some point the effect of dynamic metamorphism. The freest from it are the members of the Cortlandt series. Next to these are certain large granite masses of the Highlands belt proper, such as Storm King, Breakneck ridge, and Dunderberg mountain; but even these are dynamically affected along certain zones to such degree that the original character is wholly destroyed.

All the sediments are extensively affected. The most modified of all is the most ancient sedimentary representative, the Grenville; next is the Manhattan-Inwood-Lowerre series and least of all the Hudson River-Wappinger-Poughquag.

In the last group are occasional occurrences of shales and slates and beds of limestone and quartzite which maintain clear evidence of their original bedding and composition; but in many places the sedimentary structure is completely eliminated, the minerals are reorganized, the textural habit is entirely new, and even the composition has been altered. The chief change probably is the elimination of combined and interstitial water and soluble salts and the introduction of silica in the more open-textured beds such as the Poughquag quartzite.

This is the condition of the simplest series on the northern margin of the quadrangle, but a long wedge of the same series occurring in the Peekskill valley region has been still more modified, so that the shale-slate member is there a phyllite, with bedding structure completely destroyed, the limestone member is crystalline limestone, and the quartzite is completely recrystallized. This, however, is the normal dynamio-metamorphic effect. There is, as far as the writers know, no reason to attach great importance to contact metamorphism of this simpler series.

In the case of the mica-schists of the Manhattan-Inwood series, however, reorganization of the most elaborate sort has been accomplished. A coarse-grained schistose rock has been developed which extends in repeated belts from the margin of this quadrangle to New York City and is injected and impregnated on a most elaborate scale. It may be taken to represent an intermediate type of metamorphic rock involving both dynamic and igneous influences. In many localities, the recrystallization effect is dominant and the other either insignificant or lacking, whereas in other places igneous influence and introduction have changed the character of the rock. Everywhere all trace of the original bedding is destroyed. Everywhere all the original material has been recrystallized and great variety in quality and structural habit has resulted.

It has often been held that the Manhattan schist owes its complexity, especially its extreme recrystallization, more to igneous influence than to its dynamic history, and that the difference between the Manhattan schist and the Hudson slates is dependent upon this difference of field relationship. To what degree this may be true is discussed more fully under the topic Correlation. At this point it is sufficient to mention this additional cause of metamorphic complexity represented by these rocks.

The most elaborately metamorphosed formation is the Grenville series of ancient sediments, which are limestone, schists and gneisses in their present condition. They are the extreme in the direction of metamorphism indicated above, where contact, injection and impregnation effects are dominant over the simple dynamic and recrystallization processes. It is perfectly apparent, however, that these rocks have been modified extensively by dynamic influences. Most of the dynamic history is believed to be earlier than the igneous intrusion, but there has been so much subsequent modification that it is not possible to discriminate between the metamorphic habit developed before any of the igneous rocks were present and that which is involved with the igneous history itself. It seems certain, however, that these rocks have derived more character from their igneous relations than from their earlier metamorphic history.

On the whole, the simpler formations, such as the Hudson-Wappinger-Poughquag series, represent comparatively straightforward dynamic history and the sort of metamorphism that belongs to recrystallization of rocks under no very enormous load. There is much distortion, faulting, dislocation and flow of the softer members and differential movement between the more competent members, with the usual development of slates, crumpled phyllites, crush breccias and somewhat recrystallized limestones and quartzites.

In contrast, the Manhattan-Inwood series represents most elaborate recrystallization under sufficient load to accomplish complete reorganization, and development of high density minerals such as garnet. Mica schist, hornblende schist, limestone schist, quartz schist and crystalline limestone of coarse marble habit are not unusual — apparently recrystallized under dynamic influence. This condition prevails even where igneous phenomena are not apparent and it is therefore believed that it is not necessarily connected with that influence. But it is, at many other points, associated with igneous phenomena which do give the effects already emphasized in this type.

In the older series, the Grenville, occasional members are little affected by injection and impregnation from igneous sources, but the formation, as a whole, is very extensively involved. There is much silication of the limestone with decarbonation and development of graphite already described.

Original magmatic difference. The variations in rock quality caused by original differences of the invading magmas are not so great as those due to other causes, but there are differences of this sort and some of the peculiarities of petrographic quality are connected with them. It appears, for example, that certain of the magmatic units were exceptionally capable of invading the surrounding or overlying country rocks in an insidious and pervading way so as to mix intimately and extensively with these older members. This is particularly true of the "Canada Hill" type of granite which, as interpreted by us, was capable of penetrating all the weaknesses of the adjacent rock and introducing its own minerals, and also of absorbing great portions of this same country rock and incorporating it in its own magma. Sometimes, doubtless, nothing of the original has been preserved, but in other cases, something of the rock which was being digested remains. Where there has been failure to redistribute much of this older material, it now remains as abnormal constituents of the granite and also gives structures abnormal for a simple granite. These are more properly connected with syntexis, a topic to be discussed later, but are mentioned here as a feature particularly characterizing certain magmatic units. The result of the magmatic habit emphasized in the foregoing statement is to develop extensive and obscure granitic gneisses, the quality of which varies with the composition of the two original rocks and with the degree to which either impregnation or syntexis has developed. Elaborate gradation should be expected, in connection with such a series, from simple dynamio-metamorphic sediments and simple granites through every possible proportion of intermixed gneissoid rocks.

Other magmas appear to be somewhat less capable than the Canada Hill of penetrating or absorbing country rock, and as a result xenolithic blocks or remnants are more prominent along their borders. This difference in activity of the magmas is quite independent of any minor differences such as microscopic structures or mineral composition, although these do aid in distinguishing the individual units themselves. These small petrographic differences are, as a matter of fact, the most critical of all in identifying the different field units (see petrographic description), but they are not the cause of the variation of the series as a whole.

It is possible, of course, that a magma might develop great variation from causes such as differentiation and this is a factor to be considered, but the matter belongs to another discussion.

When magmas are less vicious or vigorous in their behavior than those just discussed or when the intrusion takes place nearer the surface they cut other formations more sharply. When such magmas penetrate other rocks, they follow structural weaknesses already established instead of soaking through the entire rock. They develop complex structural features of lit-par-lit type and tongues or stringers and dikes of still sharper margins, but have much less capacity for impregnation or absorption of the surrounding rock or of reorganizing its minerals. The Storm King granite is of this type. It has marked tendency to the development of pegmatitic habit within itself and may have influenced overlying formations by sending emanations and similar products into them. In spite of its pegmatitic tendency the formation itself lacks some of the capacity of the earlier units to modify the adjacent country rock.

It was not sufficiently fluid and vigorous. This type of behavior seems to characterize the later units rather than the earlier ones, or it may be that the portion of the older unit now exposed, was not so likely to show this behavior. Such a habit might belong to the upper portion of a mass more prominently than to the deeper portions.

The Cortlandt series as a whole is still less capable in this respect. Blocks of gneiss and schist involved in Mohegan granite are sharp-margined and not materially different from the rock at a distance from the granite, and the contact of the principal Cortlandt mass with the inclosing schist shows so little effect on either rock that typical specimens of the formations may be taken within a few inches of the margin.

It appears, therefore, that magmatic differences in the igneous units have been important factors in producing some of the rock variety of the Highlands, and it is a distinct step toward a comprehension of the meaning of the whole series and an appreciation of the genesis of some of these types to distinguish these different habits or capacities of different magmas.

Magmatic differentiation. Every large igneous unit in this quadrangle shows such continuous gradations within itself and the variety of facies is so great that it is difficult to escape the conclusion that magmatic differentiation is responsible for some of them. In the older and larger masses in particular, these gradations include wide divergence in mineral proportion or composition, difference in texture from medium fine to extremely coarse and difference in structure from massive to streaked or banded, or from uniform massive to bunchy pegmatitic and primary veined structure.

Not every formation exhibits all these habits to equal degree, but all exhibit the tendency. The Peekskill or Mohegan granite undoubtedly shows the least tendency in this direction, but even in it there are so many grades of color that the product of the quarries on a single property is assorted for marketing purposes into several grades. The variability shown by the Cortlandt series is explained more easily as a differentiation effect than as anything else. In this series norites, gabbros, peridotites, diorites and quartz-diorites grade into one another most intimately while dikes of syenitic or granophyric composition and even the Peekskill-Mohegan granite itself are judged to be differentiates of the same magmatic mass. This formation is less confused than are some of the more ancient granites, and its differentiates are readily distinguished as such. In the older members the gradations and variations are more strikingly represented, but their origin as magmatic differentiates is not so certain. For example, the more vigorously penetrating members and those which were intruded during movement, as well as those which had strong pegmatitic tendencies, have a tendency to develop extreme differences in very short distances giving a structural habit more than a differentiation effect. Wherever the structure is massive or uniform, variation is also simple and gradual, but in portions with strong gneissoid structure or strong pegmatitic tendency, the differences are more abrupt and the extremes are much greater. Judging from the structures represented, it appears that deformation during certain stages of crystallization is not only an aid to differentiation, but a very prolific cause of pronounced complicated and variable structure. It is the writers' belief that the movement represented is largely regional deformation rather than internal convection within the magmatic mass and that some of the Highlands gneisses owe their chief structural habit to this process. They are therefore apparently not simple gneissoid granites but are in part dynamic and to that degree have many of the characteristics of true gneisses. That they have not been deformed or recrystallized to any considerable amount since complete solidification is practically certain, and it is absolutely certain that their chief structure is not due to recrystallization at all. To this degree, therefore, the rocks of this structural habit and relation are more properly representatives of the gneissoid granites than of true gneisses.

It should not be concluded from the emphasis placed on this process, however, that we consider this the method by which all the streaked and banded rocks were made. As a matter of fact, it seems to us that most of them have developed under quite different conditions and influences, with the aid of syntexis, injection, impregnation and structural control from the previously existing formations. In other words, it seems to us that banded and other strong structures of the same general habit are in large part antecedent structures imposed upon the igneous mass and preserved in it even where the original mineralogy may have been destroyed.

It is scarcely within the province of such a paper as this to discuss the mechanics of differentiation and the different theories of the working of this principle, and we do not undertake to argue for or against the principle of *liquation*, or the separation of magmatic liquids of different quality, as compared with the principle of *fractional crystallization* or the separation and settling of crystals in solid phase. Perhaps both processes are represented. Perhaps the development of a pegmatitic facies is only the rejection of end-product matters from a partly solidified mass. To this degree, therefore, it is a result of fractional crystallization. It is also possible that some of the banding structure and gneissoid habit has a similar history connected with convectional movement or regional deformation during crystallization, and perhaps for some of the differences in the same structural unit one should resort to the principle of liquid separation as an additional factor. Processes of some kind connected with the differentiation have brought about marked differences of composition within short distances and these, in conjunction with movements of all kinds, have caused at least part of the complex structural variety and petrographic confusion of the ancient gneisses of the Highlands.

It is entirely possible, and indeed as we believe highly probable, that even the basic differentiates, represented by the hornblendic pegmatites and the magnetite ores, are related to one or more of the granites. If one makes allowance, therefore, for such extremes of composition it adds materially to the difficulty of drawing boundaries between formations in mapping, and it leaves one in much uncertainty about the proper correlation of many of the smaller field units. But, although it adds to the difficulty of clearly connecting individual specific occurrences, a recognition of these differentiation possibilities aids materially toward an understanding of the great complexity. And since the petrographic variation is so great anyway that it is impossible to make every variety a distinct unit, it leads to more successful understanding of the whole structure to give credit for some of the mineralogic variation and structural peculiarities to the process of magmatic differentiation.

Magmatic movement. This topic has been discussed to some extent in connection with differentiation phenomena. It is sufficient at this point to review the item for the purpose of emphasizing its comparative importance. Even the simpler granites very rarely have perfectly massive structure. They are almost universally streaked or crudely banded in a way that suggests at once some form of flowage. In some cases such structure as the rock contains seems to have no necessary relation to the dynamic structure of the region, and it may be that these portions represent simply convectional movements within the magmatic masses. But by far the more common structure is strictly conformable with the regional structure or trend and in so far as it is not derived from outside control through dissolved blocks, or is not an injection effect, it is induced by regional deformation acting on the magma during its later stages of crystallization. In some cases there are small crumples and wavy structure throughout a mass which could not be affected in that manner when solid. Again there are occurrences of pegmatitic facies of the same rock which cut squarely across these complicated structures and are not affected by them. This indicates clearly that the crumpled or wavy structure itself was developed before the rock had entirely finished its crystallization. For the pegmatites, which are the final products of the crystallization, would show the result of movement if they had been solidified at the time the movement occurred. Certain portions of the Storm King granite as well as portions of other granites, occur in this manner, and it is believed to be more common than development of gneissic structure after complete solidification.

However, deformation subsequent to recrystallization can not be eliminated as a cause of gneissic structure. It is very clear that there has been deformation, and there has been recrystallization even in some of the most substantial rocks, but for the most part these effects are either local or confined to the more incompetent members. There are few evidences of extensive recrystallization induced by regional metamorphism of the granites.

Magmatic absorption or syntexis. It seems to us that an additional process of very large influence is syntexis, or the absorbing of country rock by invading magmas. Blocks of country rock have been included as distinct xenoliths and probably no competent observer would question either their abundance or their significance. It is also clear that such xenoliths may be found in practically all stages between that of almost complete independence and little modified condition to that of almost complete destruction. It is probable, however, that not every one would be willing to believe as much as we do in the complete absorption of large quantities of wall rock, and to credit as much of the difference in quality within the igneous mass itself to this cause. But it may indeed be, that more of what appears to be a differentiation effect is really due to incomplete syntexis, with failure to redistribute the different matters that have been incorporated, than to differentiation proper. It may thus happen that much of the streaked and banded structure and of the divergent compositions and qualities may be a sort of obscure preservation of the original structure of the rock masses absorbed. Such an effect might be called an *antecedent structure* in igneous rocks. It is neither a product of differentiation nor of movement, but a structure that has been crudely preserved after the rock which it represents has been otherwise wholly destroyed; and it is a result of the failure to redistribute completely its chemical components rather than a peculiarly efficient assembling of them.

It is believed that this principle is represented on a very large scale and, to some degree, in all the formations appearing as invading igneous masses. Even the Cortlandt series has its representatives of this sort, as advocated many years ago by the senior author of this bulletin in explanation of the meaning of the emery deposits and their peculiar structural and compositional features.

The most striking representative of this habit, however, is, we believe, the type designated in this paper, the Canada Hill granite. This type, as already indicated in an earlier paragraph, seems to have been especially competent and vigorous, both as an insidious invader of adjacent country rock and as an absorber of incorporated blocks from the same source. The gradation is so complete in all stages between these two extremes of behavior that it is impossible to determine where the invaded rock, still retaining some of its old composition, stops, and the absorbed rock, representing a syntexis with nothing left but the so-called antecedent structure, begins. That both are largely represented we feel certain but the appearance is so similar and the structure and composition, even in minor detail, are so nearly alike that no adequate criteria have yet been discovered for their discrimination. Here again, an understanding appreciation of a principle or process is a great satisfaction and aid in interpretation of the complexities encountered in the field, but accurate discrimination between individual specimens is often impossible.

Igneous injection. It is well understood that certain very fluid types of igneous magmas show great vigor in invading adjacent rock, and seem to find all sorts of obscure weaknesses along which to thrust themselves. In a general way, even those magmas not strikingly capable in this direction are able to penetrate or cut through overlying or adjacent formations. In this sense, all the igneous masses in this quadrangle are intrusions, but only those of comparatively high fluidity succeed in penetrating vigorously enough to become distributed in small masses through long distances. Such a tendency normally develops a striking banded habit if the injections are repeated or occur at small intervals, and results in the so-called *lit-par-lit* injection structures. Such action is not confined, of course, to a single invading magma or to a single epoch, and in a district with as complicated a history as this, such injection processes might be repeatedly set in operation by succeeding magmatic invasions. In such cases a rock would become exceedingly complex and even an ordinary museum specimen might represent not only the original country rock that preceded all the injections but additional material from each succeeding igneous invasion. Occasionally these individual portions are in large enough bands or are striking enough in their petrography to be correlated with their source. But in many cases it undoubtedly happens that differentiation of the invading fluid and its contamination by absorbed material together with recrystallization of some constituents have given a rock which is not readily assigned to a particular type. Clear cases, however, are so frequent that there is no doubt of the importance of the injection process in the manufacture of the banded gneisses of the Highlands. It is our belief that the strongly banded gneisses are more frequently of this origin than of any other simple origin, that next to this process in the matter of competence to develop a banded structure is syntexis, and that differentiation proper is the least efficient of all. Injection phenomena are not difficult to understand and in many cases are readily recognized, but in many of the complicated gneisses of the Highlands the confusion is so great that it is impossible to indicate with certainty which structures are due to one type of origin rather than another. It is a process the understanding of which helps very materially toward an accurate working conception of the meaning of the geology of the Highlands, but in detail, in a minor way, the complete statement for every outcrop is absolutely impossible.

Igneous injection is related to magmatic differentiation, to syntexis, to magmatic movement and to igneous impregnation and contact effects. These are as a matter of fact only the different expressions of the whole complicated process of deep-seated rock-making during igneous invasion.

All the ancient granite magmas have developed injection phenomena, but it is more noticeable with the Canada Hill type, the older diorites, the Reservoir type and the Storm King. The Peekskill-Mohegan granite and the Cortlandt norite series have had little injecting power.

Igneous impregnation. We are using this term to distinguish insidious interpenetration of magmatic matters from the simpler injection type just described where, as a rule, the introduced material is distinguishable from the country rock. In true impregnation the material that is introduced is capable of entering the interstitial

Plate 3

Pegmatitic granite injection of an older granitized injection gneiss.

This is a loose block lying on ledges of Reservoir granite near Peekskill. The latest injection member is judged to belong to the Reservoir granite, and the older portions are remnants of Grenville metamorphics granitized with Canada Hill granite. The block therefore represents and illustrates the relations of three of the important members of the Highlands series of rocks.

spaces between the grains of the older rock and of penetrating its most minute structural imperfections and, in extreme cases, of literally saturating the original rock. In its simplest form this process resembles induration and silicification where materials are simply added. In its somewhat more elaborate form it is a selective replacement. In its most complicated development it is accompanied by absorption, by replacement and by contact metamorphic effects which transform the original rock into a mixed product. This is in part made up of remnants of former minerals, in part of syntectic products, and in part of materials that represent the invading igneous masses.

Doubtless very fluid condition and high content of mineralizers or emanations, together with high temperature and great depth or pressure, are conditions favorable to such type of penetration. Certainly not all igneous masses exhibit any such tendency in their field occurrence, but some of them do and an occasional one exhibits this behavior to a very exceptional degree. The most efficient unit in the West Point area seems to be the Canada Hill granite. It has been mentioned before as showing competence in absorbing the surrounding rock, but it probably was equally vigorous in sending out invading substances which penetrated the older Grenville series most complexly. It thus happens that it is impossible in some places to decide between the conflicting possibilities of rock origin, because the rock may be partly metamorphosed sediment and partly true igneous. These two representatives have so intimately intergrown that the rock is now as simple looking as some of the direct differentiation products or some of the metamorphics. The types of original rocks most readily invaded in this way seem to have been the granular fragmental ones or the shaly or schistose ones, but the effect is sometimes noticed even in the limestones, and it is not unusual to find an abnormal carbonate content in a rock that otherwise looks like a granite gneiss. Such rocks should be called granitized rocks if the invading substance is of granite composition, but there seems to be no general term for the process as applied to all magmas. Granitization, however, stands reasonably well for the results secured in this district, because certain of the granites give the most conspicuous examples of the working of the process. Farther to the south the same habit appears in connection with pegmatite development in certain portions of the Manhattan schist. These pegmatites have soaked through the schist in an almost unbelievable way and to such large amount that in places the schist is more than half granite. That formation has not been so affected within this quadrangle but very elaborate granitized effects are produced in what was once the Grenville.

A peculiar form of this impregnation process appears in connection with the Cortlandt series, where xenoliths were partly absorbed. It is believed that those are the places that have developed corundum, emery and spinel and are the sources of the emery deposits of the Peekskill district. The process of impregnating the original rock together with the selective removal of material from it has developed these unusual constituents. None of them appears in either the original schist or the original norite, but they are found where traces of syntexis and impregnation are in evidence.

It is possible that other impregnation effects are selective in their nature, that in most cases part of the country rock has been completely removed while new material has come in, and that the minerals finally left as the additional constituents are only a part of those which passed through the particular spot.

Granitization of limestones is apparently a much more difficult thing to accomplish, and it is seldom observed in this or adjacent districts. Farther to the south in the Harlem quadrangle, however, where thin limestone beds are associated with gneisses, and where both injection and impregnation gneisses are developed, a case has been found where a limestone layer was transformed into a slightly banded granite gneiss, the change taking place within a distance of 30 feet. It is therefore difficult to escape the conviction that granite impregnation has been a very important process in the transformation of many of the ancient rocks of this district. The older granites have apparently been the most efficient, and the youngest ones decidedly less so. The Peekskill-Mohegan type is practically free from important effects of this kind.

Contact effects. In a district where igneous invasion has been developed on as large a scale as in this West Point area, one would expect to find some evidences of contact metamorphism. Such effects are found, but not on as large a scale or as clearly defined as other districts have produced. Perhaps it is somewhat more accurate to say that most of the contact metamorphism that has been effected is either so intimately involved with the processes already enumerated, or the connection of the metamorphism with any particular igneous influence is so obscure, that one feels uncertain about the amount of modification to be attached to this cause. To a certain degree the process referred to above under the heading "Igneous impregnation" is a part of a series of effects usually assumed to belong to contact metamorphism. In so far as the materials introduced in this way combine with those already in the rock to make a new product, the classification holds strictly true, but in so far as the impregnation results simply in the penetration of the rock by the regular igneous rock minerals which crystallize there, it is a question whether contact metamorphism is a suitable term.

The strong schistosity of certain parts of the Grenville suggest that regional metamorphism had accomplished a great deal, and that contact effects are supplementary rather than fundamental. If one includes injection and impregnation phenomena with the contact history, however, then certainly in many places contact effects are dominant, and original regional recrystallization of secondary importance. But it is unlikely that the structural results now shown would have been attained if the older formation had not originally been schistose, crystalline and folded.

As usual the limestone beds show the best evidences of contact metamorphism in this series, and extraordinary complexity of appearance and composition is a common development.

Contact metamorphism of earlier granites and gneisses by later granite magmas is very obscure and the later granites such as the Peekskill-Mohegan have little apparent effect. Even the xenoliths in this formation maintain their identity and appear to be of exactly the same character as adjacent rock of the same formation not thus exposed. The Cortlandt series accomplishes more on the xenolithic masses of schist that have been engulfed. Some are not only completely transformed in mineral constituents, but also show selective elimination and addition of material from both the original rock and the igneous host. Thus it happens that an abnormal composition results with corundum, emery and spinel, none of which belongs typically to either rock.

It is held by some geologists who have studied southeastern New York that the coarsely crystalline habit of the Manhattan schist, which differs so markedly in this respect from the Hudson River phyllite, is due chiefly to the influence of invading igneous matters or to subjacent magmatic masses which have induced more thorough crystallization. This view, therefore, would credit the highly crystalline character of the Manhattan formation chiefly to influences that may be classed with contact metamorphism. The writers do not seriously question the competence of contact influences to accomplish such differences of condition, or degree of reconstruction, but they doubt the appropriateness of the explanation for the crystallinity of the Manhattan mica schist.

In review of this point, therefore, it is proper to emphasize the fact that the usual silication and silicification or induration effects, as well as more elaborate and obscure recrystallizations, are in places evident and doubtless are of contact origin. This is not the only cause, however, of recrystallization, and it is therefore not always possible to specify to what degree the various schists, gneisses and limestones owe their present peculiarities of composition and structure to contact metamorphism.

Dynamic influences or deformation. It is not the purpose at this point to discuss the larger features of structural geology as dependent upon the deformation history, but rather to enumerate and compare the ways in which deformation has accomplished petrographic variation or modification. It is the writers' belief that a very ancient dynamic history is responsible for the original structural quality of the oldest formation, the Grenville. It is our opinion that the deformation of that period developed foliated and folded rocks. The same influence is likewise in control of the petrologic quality of the Manhattan-Inwood series. To a much smaller degree also, a tendency to this same sort of development is to be seen in the Hudson River-Wappinger-Poughquag series.

In connection with this deformational history, folding and faulting have resulted, the effects of which give some of the most striking geologic features of the West Point area. In certain of the weaker members, fine crumpling habit is developed and similar structure may rarely be seen in some of the gneissoid rocks believed to be essentially igneous. In the latter case it is believed to be due to deformation, perhaps of a regional sort, occurring when the rock mass was only partly solidified.

We are not able to determine whether these dynamic influences referred to above as probably regional are connected instead with the crowding action of invading and intruding magmatic masses. Probably both have figured, but it seems to us that the regional influences are large and that the crowding and shouldering effects of igneous masses are probably comparatively insignificant. It is not clear, however, just how one could distinguish with certainty between them.

The larger deformation movements have at times been concentrated in certain zones along which remarkable deformational effects are recorded. Some of the most elaborate transformations take the form of shearing, granulation and recrystallization (see plate 40); and where the conditions are not so favorable for this minute structural effect, crush zones are developed with completely recemented crush-breccias. Such products have been secured from the Storm King granite, indicating deformation of this formation under rather deep-seated conditions.

All stages of dynamic disturbance are recorded in these rocks, from strain of the constituent minerals observable only in the microscope to completely mashed material. Recent experience in connection with certain engineering projects indicates that these strain effects are accumulated to great intensity along certain belts and that at considerable depth beneath the surface, in deep shafts and tunnels, these overstrained zones develop the peculiar "popping rock." This seems to be the result of the disturbed equilibrium produced by removing part of the original support of the rock in these excavations. In such places new slabs break off along lines quite independent of the other structural lines of the rock and in the most pronounced cases add much to the danger and difficulty of deep underground working. (See discussion of Hudson River crossing in the chapter on engineering geology).

The zones which have shown excessively strained conditions at depth are probably represented at the surface by the close-set parallel joints or sheeted structure that is repeatedly observed in all the massive rocks. A region where the most substantial rocks have such a condition irregularly distributed can hardly be considered to have reached any very high degree of stability. It is either accumulating additional strained condition, which may ultimately overcome the strength of the rock and require readjustment, or else it is a remarkably well-preserved residue of much older dynamic impressions still held in the most massive rocks. Molecular readjustment is doubtless going on, but the normal resistance to such reorganization in the most massive rocks may account for all this lagging of deformation.

Formational groups of larger petrographic significance

The more important rock classes representative of the great variety which actually occurs are the following:

a Sedimentary and organic rocks (little metamorphosed)

b Sedimentary and organic rocks (much metamorphosed)

c Contact and metamorphic products of complex origin
d Deformation products (shear schists)
e Igneous types
f Mixed types

The chief representatives in these different classes need little individual treatment because the mappable formations are discussed in the section immediately following. But as a matter of petrographic distinction, and as indicating the petrographic range of the district, it may be useful to make a preliminary list, noting separately the varietal types of each genetic class.

a **Sedimentary and organic rocks (little metamorphosed).** This class includes a large development of quartzites, represented by the Poughquag formation, a larger development of limestones, represented by the Wappinger formation, and a still larger development of slates and graywackes and more rarely of phyllites, represented by the Hudson River formation. All these are somewhat affected by metamorphism which has reorganized the original material more or less and developed new structural quality. This is least apparent in the quartzites and most prominent in the phyllites. Some of the quartzites are sandstones, but in places of greater dynamic disturbance there is much tendency to recrystallization, the quality depending upon the original make-up of the rock and the dynamic history of the particular spot from which it was derived. The slates are much more variable and range from simple fine black slaty shales to very siliceous and granular beds in which the material has been considerably reorganized, but which have no slaty cleavage. The slates are the most variable and show the dynamic influence more than the other types in this class.

The phyllites are more completely modified from their original condition than any of the other rocks of this class. They represent metamorphosed slates and are found only in the downfaulted block bordering the west side of Peekskill Hollow creek valley and in the continuation of the same block on the west side of the Hudson at Tompkins cove. The most completely recrystallized limestones and quartzites are associated with the phyllites in this valley. A great variety of sedimentary representatives can be secured from the series. They are all of undoubted Cambro-Ordovician age. Simpler types than these are not known since no simple unmodified sediments except those of glacial and postglacial age occur within the boundaries of the West Point quadrangle.

b **Sedimentary and organic rocks (much metamorphosed).** This class is represented in the southeast quarter of the quadrangle, by the Manhattan-Inwood series, and by a strip of Grenville along the Hudson river, with occasional other smaller patches. It includes thoroughly crystalline limestone or marble, recrystallized quartzite, and schists of great variety — chiefly mica schists, quartz-mica schists, and hornblende schists, all of which blong to the Manhattan-Inwood-Lowerre series.

Gneisses of the greatest possible variety and associated schists and rocks derived from limestones are represented in the Grenville series. They include coarsely crystalline marbles, silicated limestones of great variety, banded gneiss and schistose rocks. It is impossible in this case to draw the line sharply between the sediments that have been metamorphosed by the simpler processes and the contact metamorphic products of complex origin. As a matter of fact, they are close associates.

c **Contact and metamorphic products of complex origin.** This class includes limestones that are thoroughly silicated and represent typical contact influence and rocks that have been impregnated and injected by igneous materials. These rocks have been discussed in the earlier portions of this chapter. The products are chiefly gneisses of great variety in quality and composition and structure. Garnet is often developed and doubtless many of the constituents are combination products representing neither the original materials nor the introduced materials alone. In this class is still greater variety in minor ways than in any other of the groups listed, but all have the complex metamorphic type of origin.

This class is represented by the banded and streaked rock common in the Highlands and is the basis of the term often used — the Highlands gneisses. It is still more typical of the Fordham gneiss, which is the name used in the New York City area.

d **Deformation products.** Along lines of weakness or deformation zones, particular qualities are developed which are found nowhere else in the region. These are directly the products of deformation and include shear schists and granulation gneisses. The particular quality depends on the rock originally involved and on the extent of the deformation and the balance between purely mechanical effects and recrystallization. There is, of course, no great areal extent of such products and none is mappable, but they form beautiful petrographic varieties of much interest.

e **Igneous rocks.** These occur in great variety, and represent either plutonic or large intrusive masses or small dikes or veins. No surface flows are represented in this field.

The acid type includes granite, alaskite and aplite.

The intermediate type includes syenite and syenite porphyry.

The medium basic rocks include diorite, norite, quartz-diorite and camptonite.

The more basic group includes gabbro norite, pyroxenite and dunite.

Each principal type of rock is represented in the field by numerous facies covering a wide range of mineral proportion and habit. The actual number of varieties would be very great.

The most variable differentiates are pegmatites varying from simple quartz pegmatite to hornblende rock and magnetite ores. Some of these occur as veins, some as dikes and some as injections and impregnations.

f **Mixed types.** Mixed types are in part listed under *d*, but they include certain ones not mentioned there, especially the syntectics, which may appear as granite gneisses or gneissoid granites, the injection gneisses which are usually strongly banded, and the silicated metamorphics, chiefly represented by the Grenville series and xenolithic masses.

The Mappable Formations with their Petrography

The formations discussed under this heading occur in large enough development to require representation on the areal map. The chief bases of delimitation are: (*a*) unity of origin, (*b*) like structural or field relations, and (*c*) petrographic constancy. But in some cases the petrographic variety is so great within a single unit that this last principle of identification alone would not suffice.

On this account, the mapping of the region is difficult. The formations themselves have great obscurity and exceedingly great complexity as indicated in the preceding discussion; these conditions make the problem of dividing them into definite units for mapping, more or less uncertain. The result is a generalization, necessitated by the limits imposed by the map itself. Small differences can not be mapped on a moderate scale; only the large divisions considered of primary importance can be taken into account and indicated.

It has been necessary, therefore, to study the region with the object in mind of determining those characteristics indicative of the history of each formation and to apply them as well as possible to the delimitation of formations. These characteristics are discussed below. The units that deserve discussion on this basis of unity of origin are described in some detail in the pages that follow.

The Grenville series. The Grenville beds are the dominant type in a belt about 2 miles wide along the Hudson river from Fort Montgomery to Cold Spring. There are good exposures along the New York Central Railroad from Garrison to Manitou (Highland station) and along the West Shore Railroad north and west of Fort Montgomery, along the Garrison cut of the Catskill aqueduct, and on the state road between Nelson Corners and McKeel Corners.

The series is made up primarily of calcareous, micaceous and quartzitic beds which weather easily. Consequently this formation tends to form depressions, except where granitic intrusions have hardened it.

The Grenville is the oldest formation in the Highlands and therefore has suffered all the dynamic disturbances of the district, and is cut by all the intrusives. As it was initially a series of impure limestones, shales and sandstones the resulting product is of very complex composition. It would be impracticable to discuss all the varieties of metamorphic rocks produced, but the major processes involved are treated elsewhere in this bulletin and some of the more typical rock representatives are described below.

In the outcrop the formation commonly shows as a series of banded, crumpled and distorted rocks which weather characteristically to a mottled black or a rusty brown color. The decomposing mica (phlogopite) adds streaks and patches of a peculiar greenish yellow so that the whole complex has an appearance markedly different from that of any other formation of the quadrangle. The massive limestones weather white, with the more resistant silicates standing out in yellow to brown or greenish lumps above the surface. The color of the weathered surface, and the graphite, serpentine or tremolite always present are sufficient field criteria for determination of this series.

The disturbed condition of the beds along the Hudson river is probably a local deformation, as the Grenville seen along Sand Spring brook and Round hill is rather massive and blocky.

Types of Grenville. Some of the characteristic types of the Grenville are described more fully below.

Type a. Diopside-quartz rock.

This is a dense, hard, light-colored, greenish gray rock. It is a rather fine-grained aggregate of greenish pyroxene crystals in a quartz matrix. There are minute specks of brown titanite and of pyrrhotite and occasional coarsely crystalline patches of dull-green pyroxene with large grains of pyrrhotite. Another variety of this rock is composed chiefly of grains of colorless pyroxene, probably diopside, with rather simple noninterlocking boundaries. The interstitial spaces are filled with an aggregate of zoisite, quartz and carbonate which appears to be secondary. Small rounded titanite grains are abundant. There is an occasional pyrite or pyrrhotite grain.

Type b. Quartz-epidote-schist.

The rock is a dense, siliceous, fine-grained schist with alternating crumpled yellow-green and dark-gray bands.

It is a fine-grained, quartz-epidote schist, showing granulation of the epidote. Interstitial spaces and lines of weakness are filled with quartz. The quartz bands show considerable contortion, but the quartz is not granulated. It has rather the appearance either of vein quartz or of having been introduced while the rock was being sheared.

This deformation effect is still more strongly exhibited in thin section than it is in the hand specimen and it is from the microscopic examination particularly that the suggestion has been derived that the deformation represented is in part older than some of the injection material. (See accompanying photomicrograph, plates 4 and 5.)

Type c. A graphitic diopside rock.

A light-gray, hard, rather coarse-grained rock made of a gray pyroxene and flecked with shining scales of graphite.

The rock is coarse-grained, made of slightly clouded diopside and graphite. It must have been developed by metamorphism from a carbonaceous limestone. Both regional and contact effects are probably present in this rock.

Type d. A silicated limestone.

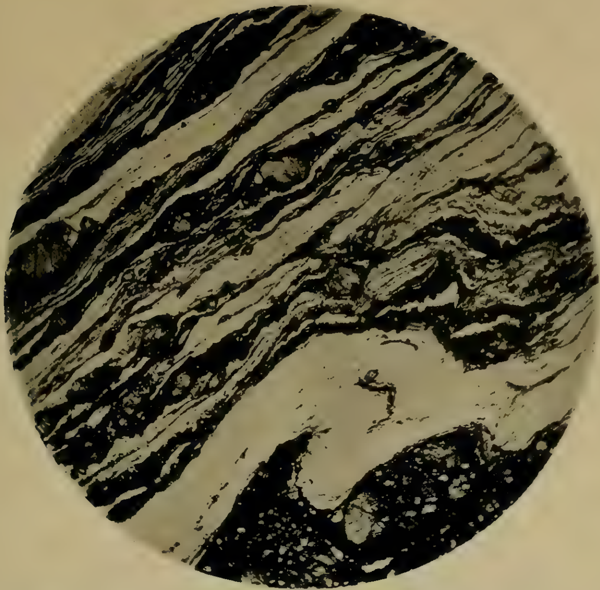
The rock is a limestone, very much sheared so that the calcite is not coarsely recrystallized, but retains all the effects of strain. It contains some quartz and a few diopside grains, iron-stained along the twinning bands.

Type e. Serpentinous limestone.

Rather massive, serpentinous limestone, of variable texture, specked with pyrrhotite.

The rock is a medium-grained limestone with large, rounded, serpentine aggregates pseudomorphic after olivine. Small chalcopyrite veinlets cut the calcite.

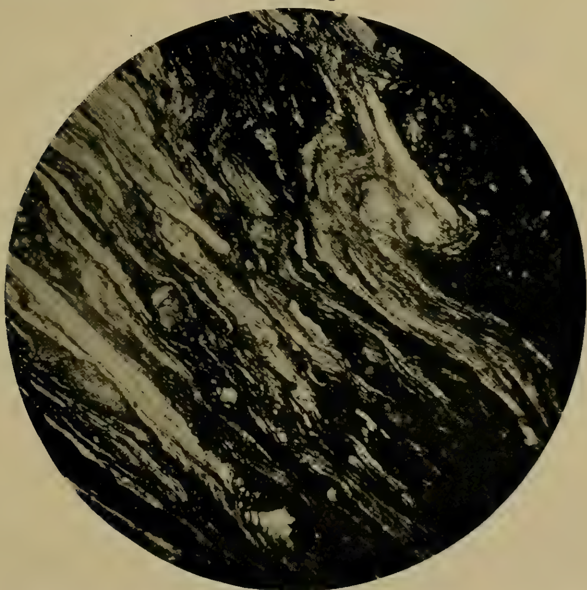
Plate 4



Photomicrograph of specimen no. 100-*b*. A shear-zone schist. Taken with plain light, magnification about 30 diameters. A specimen of Grenville epidote schist from a shear zone.

Taken to show the fine structure of this rock with the minor crumpling and augen or mortar structure characterizing this material. The composition is chiefly epidote and quartz.

Plate 5

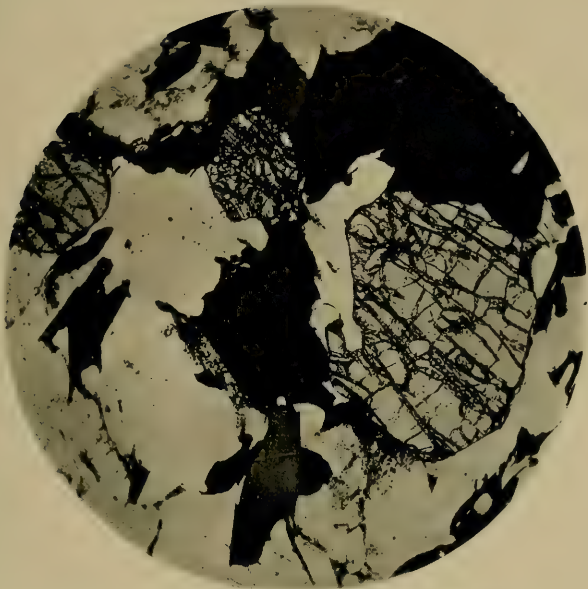


Photomicrograph of no. 100-*b*-*x*. Same as 100-*b*. With crossed nicols, magnification about 30 diameters.

Taken particularly to show the detail of minor structure within the quartz bands of the same specimen 100-*b*.

This is vein quartz probably derived from the invasion granites, and the epidote and other constituents are products of anamorphism under the same influences. These points suggest deformation of about Canada Hill age.

Plate 6



Photomicrograph of no. 143. Grenville gneiss. Taken with plain light, magnification about 30 diameters. Quartz-biotite-garnet-gneiss.

Taken to show the habit of the rock and especially its content of garnet.

The constituents are quartz, orthoclase and acid plagioclase (all clear and smooth in this photomicrograph), biotite (dark gray and black plates), and garnet (gray rough grains).

Type f. A garnetiferous gneiss.

Medium to fine-grained foliated quartz-feldspar-biotite rock, spotted with large half-inch garnet-biotite patches, intergrown with sillimanite needles.

The essential minerals are coarse red-brown biotite, garnet and plagioclase. Accessories are magnetite, zoisite, microcline, yellow brown hornblende. The biotite and plagioclase grains are bent. The biotite is oriented and interstitial. The garnet is confined to large spot of very coarse-grained garnet and biotite, which is the same as that in the groundmass. (See accompanying photomicrograph, plate 6.)

Type g. Graphitic amphibolite.

A dark-green, coarse-grained foliated rock, composed almost entirely of chloritized uralite and graphite. The foliation is produced by bands of different widths which apparently were originally amphibole and pyroxene.

Some of the Grenville rocks are not so abnormal in composition as those noted above. Most of them, however, are schists of some description unless they are heavily impregnated with minerals of magmatic source. Such a schist is shown in the photomicrographs of no. 511 (plate 7) which is a mixed schist.

Impregnation and injection and absorption products occurring in the same formation show a still greater variation such, for example, as that exhibited by the photomicrograph of no. 512 (plate 8) which has some of the earmarks of igneous addition. As a matter of fact, it is probably chiefly igneous representing some extreme of differentiation or selective injection whose source is believed to be the so-called Pochuck diorite intrusive member.

Those portions which are gneisses rather than schists are less striking in microscopic features, but all tend to exhibit suggestive content, such as the photomicrograph of no. 301 (plate 9) which is a sillimanite gneiss, or the hornblende-biotite gneiss represented by no. 501 which is probably impregnated with Pochuck diorite. (Plate 10.)

The older igneous series. *Pochuck diorite.* It is judged that the oldest igneous representative distinguishable in the area is essentially a diorite. In this quadrangle it is practically always intimately associated with streaked and banded varieties of rock of the character belonging to Grenville metamorphics. It nearly always has the appearance of a gneiss and the composition, although very variable, includes hornblende, pyroxene and plagioclase feldspar as the dominant constituents. The occurrence of pegmatitic facies is judged to support the interpretation given that igneous injection and impregnation of the original Grenville sediments by a magma of dioritic composition has been responsible for all of these effects. In some places it varies even to the composition of a soda granite.

In its simplest form, however, the rock presents the appearance of a somewhat modified diorite, medium to somewhat basic plagioclase is prominent, augite and hornblende are usually both present and the other constituents vary greatly.

Generally the relation of this igneous member to other igneous representatives is obscure. The somewhat more intimate penetration of the diorite and the comparatively clear-cut relation that certain of the granites bear to this diorite gneiss supports the conclusion that the diorite invasion was the earliest of all (see mixed types, p. 57, for additional detail).

Canada Hill granite. The Canada Hill granite, as exposed typically at Kings quarry south of Garrison, is a medium gray, medium-grained rock varying from faintly to very perceptibly streaked. It is composed of white and gray feldspar, gray quartz, small crudely oriented biotite crystals, and numerous small, rounded, violet-red garnets.

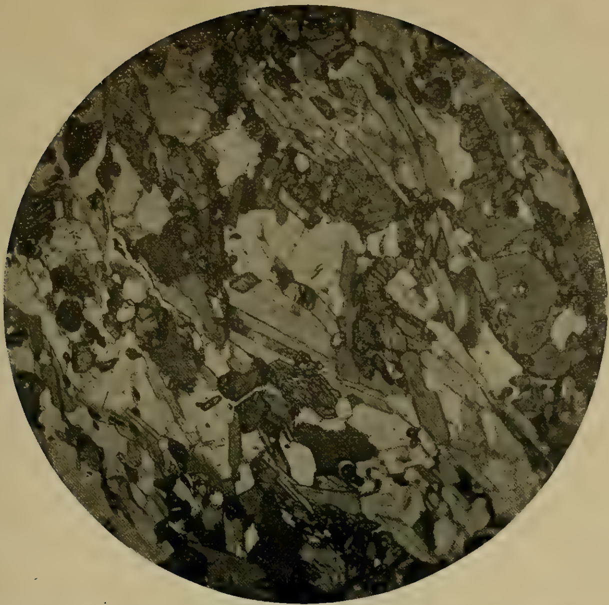
There is also a pegmatitic facies which is coarser-grained, grading into true pegmatite. It is penetrated by or streaked with white segregations of quartz and feldspar, resembling alaskite, carrying large patches of red-brown garnet aggregate.

The weathered surface is dull gray. The feldspar and biotite weather out leaving the quartz and garnet. The new fracture in the weathered rock has a faintly pinkish or yellowish tinge. The mica is bleached yellow and carries rutile, the feldspar is rather chalky, and the gray quartz and dull-red garnets stand out clearly.

This type represents the oldest and most vigorous of the granite magmas which have invaded the ancient complex of this district. Microscopically the rock varies greatly. On the whole, however, it is medium grained with remnants of dusty looking orthoclase as a prominent constituent with much fresher looking microcline with soda feldspar comparatively common, and abundant reddish brown biotites carrying numerous oriented rutile needles. Quartz also is a prominent constituent.

A characteristic appearance and composition is shown by no. 440 (plates 11 and 12).

Plate 7

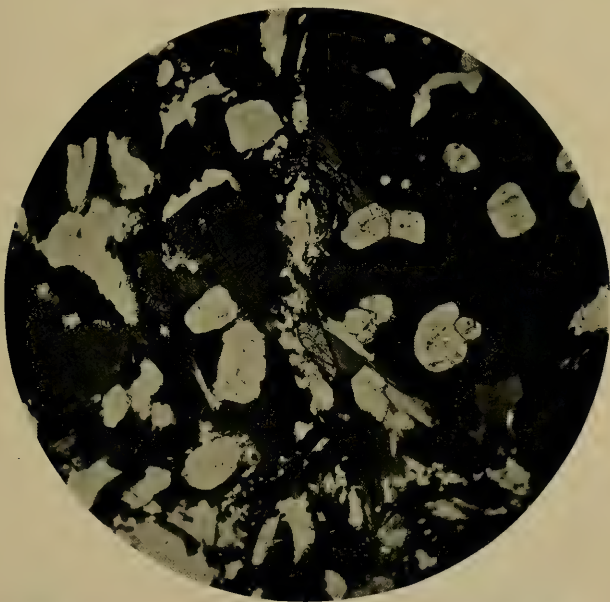


Photomicrograph of no. 511. Grenville from east side of quadrangle. Taken with crossed nicols, magnification about 30 diameters.

Showing a typical very complex make-up and comparatively fine grain.

a Quartz — abundant (clear). *b* Plagioclase feldspar much less abundant (clear). *c* Biotite very abundant (gray plates with cleavage). *d* Hornblende, abundant (dark). *e* Titanite abundant (very rough, small gray grains). *f* Magnetite (a little) (black). *g* Apatite (high relief, clear and small grains).

Plate 8



Photomicrograph of no. 512. Injection facies of Grenville from east side of quadrangle. Probably a Pochuck injection product. Taken with plain light, magnification about 30 diameters.

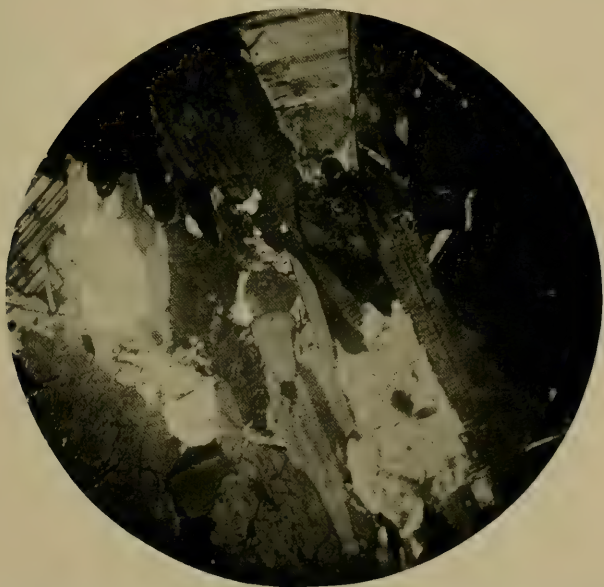
Showing a rather massive type with abnormally high apatite content. *a* Biotite abundant (dark smooth and in plates). *b* Hornblende abundant (dark with coarse cleavage). *c* Apatite abundant (high relief, colorless grains in the hornblende and elsewhere). *d* Quartz (few clear grains). *e* Pyrite (large black grains). *f* Titanite (very rough). *g* Magnetite (a little) (black).

Plate 9

Photomicrograph of no. 301. Grenville gneiss. Taken with plain light, magnification about 30 diameters.

Taken to show a specimen of quartz biotite sillimanite gneiss. The constituents are quartz and feldspar (light smooth areas) biotite (black) sillimanite (light high relief rods).

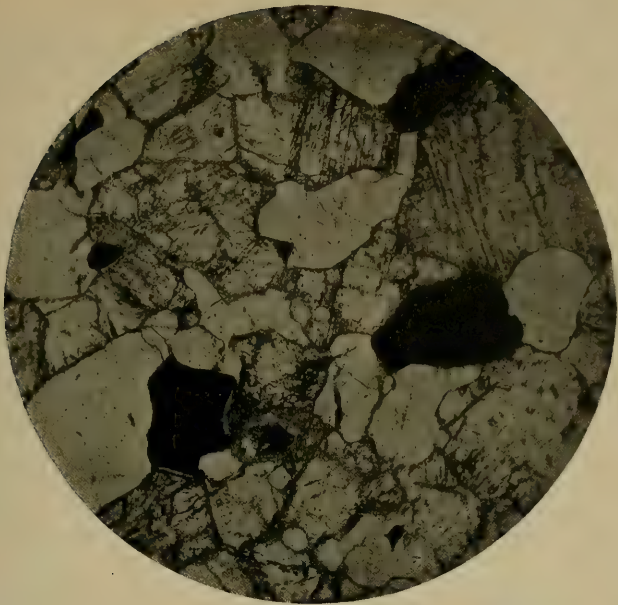
Plate 10



Photomicrograph of no. 501. An injection facies of Grenville from east side of quadrangle. Probably largely Pochuck diorite in present make-up. Taken with crossed nicols, magnification about 30 diameters.

Showing: *a* Gneissic structure. *b* Abundant plagioclase (banded). *c* Abundant hornblende (dark and rough with cleavage). *d* Abundant biotite (dark mottled with cleavage). *e* Much less abundant quartz (clear). *f* A little magnetite (dead black).

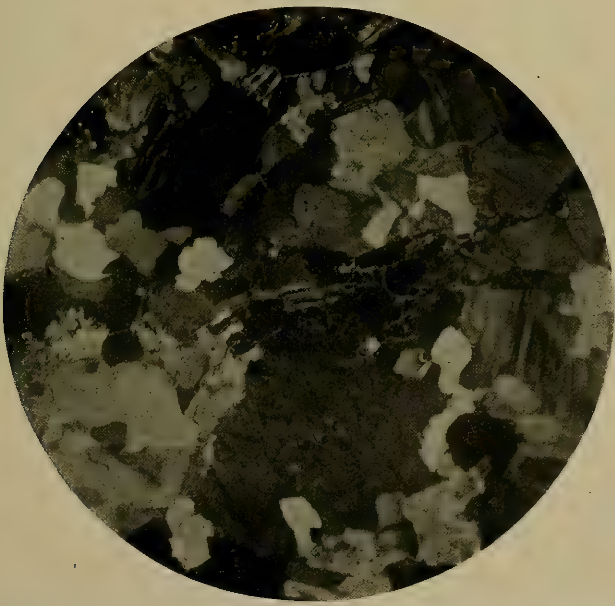
Plate 11



Photomicrograph of no. 440. Canada Hill granite. Taken with plain light, magnification about 30 diameters.

Showing the typical habit of the Canada Hill type of granite: *a* Dominant feldspar, showing plainly in the field because of slight sericitic alteration (gray grains). *b* Prominent quartz (clear, nearly equidimensional grains). *c* Biotite flakes with prominent sagenite structure of crossing rutile needles (black in this reproduction). This rutile content and the slightly modified appearance of the feldspars is a very characteristic mineral habit of the Canada Hill type.

Plate 12



Photomicrograph of no. 450-*b*. Canada Hill granite from Kings quarry. Taken with crossed nicols, magnification about 30 diameters.

Taken to show the distribution of feldspar and quartz constituents and the general structure of the rock. The chief feldspar is microcline. Quartz occurs in small irregular grains. Biotite is in oriented plates. Three crystals of garnet occur in this field (black in this light).

Reservoir granite. The Reservoir granite is one of the most widely distributed granites of the Highlands. It is this rock together with the Canada Hill type which has done most of the granitization of the Grenville. It is commonly found penetrating and invading the older rocks, and is seldom found perfectly free from traces of the gneiss. The best exposure is at the north end of Boyd Corners reservoir where the granite can be seen to be an igneous rock intruding the gneisses. A smaller exposure showing the rock type fairly well is at the bridge across Conopus creek, east of Dennytown.

It is a rather coarse-grained, gray, gneissoid granite. At first sight it appears to be a true gneissoid granite, showing marked flowage effects, and cut by numerous pegmatite and quartz stringers. The pegmatite is much crumpled and distorted, but the quartz cuts straight through all the other structures. On further examination large included blocks of dark, banded gneiss are seen. They are crumpled and distorted and contain within their margins all the observed pegmatite. They are in reality in all stages of assimilation and grade from almost angular pieces with distinct outlines to pieces so completely dissolved in and penetrated by the granite that they would be indistinguishable from it were it not for the pegmatites which remain unaffected. In the partly dissolved pieces there is a perfect transition from gneissoid granite to gneiss and the flow structure of the granite is in every case parallel to the original crumplings in the gneiss. The granite is therefore a syntectic. The structure is not its own, but is imposed by the invaded gneiss. (See discussion of the processes of petrogenesis, especially syntexis, impregnation, and the development of internal structural habit, page 29.)

The typical Reservoir granite as exposed at Boyd Corners reservoir has a rather coarse texture of white feldspar striated and unstriated, and a very little quartz, and is strongly marked with oriented streaks and patches of deep-brown mica. It is spotted with the same small purplish to dull-red garnet as the Canada Hill granite. It has a tendency to break roughly along the mica planes, giving a mottled appearance to the rock. It varies from this to a finer grained, more definitely banded rock, produced by shearing. There is, even at the reservoir, a slight tendency to the development of the pink feldspar which becomes in the Mahopac granite a prominent constituent of the rock. It differs from the Canada Hill granite in its higher biotite content, and in the greater continuity of the mica bands. But the mica content is not constant and some specimens are difficult to distinguish from the Canada Hill.

In thin section it is seen to be a medium-grained granitoid rock composed of orthoclase, acid plagioclase (albite and oligoclase), quartz, biotite, epidote and zoisite, and in some specimens a blue soda amphibole. The accessory minerals are apatite, garnet, muscovite, titanite, rutile in the form of sagenite, and rarely allanite.

The peculiar habit of the feldspar serves to distinguish this from the other rocks of the region, especially in these two points:

1 They are extremely poikilitic and contain countless small inclusions of zoisite and mica which vary in size from a fine dust to clear, well-formed crystals.

2 The feldspars show strong granulation of the edges of the crystals (mortar structure). In some cases the entire crystal has been broken up. Part of the quartz shows this effect, the rest of it with the biotite and epidote, occurs undisturbed distributed through the interstitial crushed feldspar material and along the crush lines.

The foliated appearance of the rock is caused by the orientation of the mica.

The quartz which has not been crushed is of the vein type with marked wavy extinction. The biotite is of a greenish brown color, not strongly pleochroic. It is occasionally intergrown with muscovite and frequently with epidote. It occurs in two generations, as inclusions in the feldspar and as a late product of crystallization. The epidote or zoisite is variable in amount and character. It, like the biotite, occurs in two generations — a fine inclusion in the feldspar, and a coarser grained associate of the interstitial biotite and quartz. The garnet is in medium-sized grains, of a faintly pinkish color, in rounded but poorly developed crystals.

Some of these characters are shown well by the accompanying photomicrographs.

No. 430-*a* (plate 13) is taken to show the prominence of the zoisite grains referred to in the general description.

No. 332-*a* (plate 14) shows a typical granulation effect.

No. 16-*b* shows a case where strong schistosity is developed in addition to granulation (plate 16).

No. 430-*b* (plate 15) is another variety with both garnet and allanite.

Mahopac Granite. The rock is a medium-grained, pinkish, gneissoid granite, distinctly but not strongly foliated. It is made of colorless quartz, slightly pink feldspar, and dark biotite. The biotite is in rather fine bands, more abundant than in the Canada Hill granite,

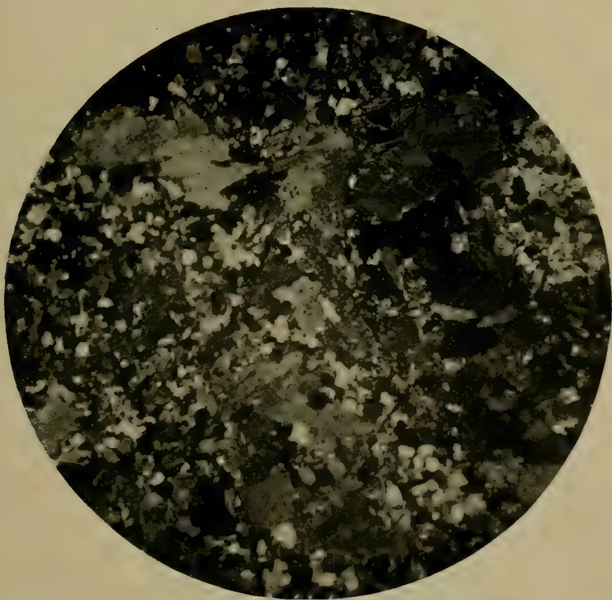
Plate 13

Photomicrograph of no. 430-*a*. Reservoir granite. Taken with plain light, magnification about 30 diameters.

Taken particularly to show a prominent feldspar area with orthoclase and soda plagioclase, a small amount of quartz and biotite with very complex development of trains of zoisite particles in parallel and crossing streaks following former fractures and weakness lines through all of the feldspars.

In other slides some of the rock is granulated. In this there is very little if any granulation, but very prominent development of these trains of inclusions.

Plate 14

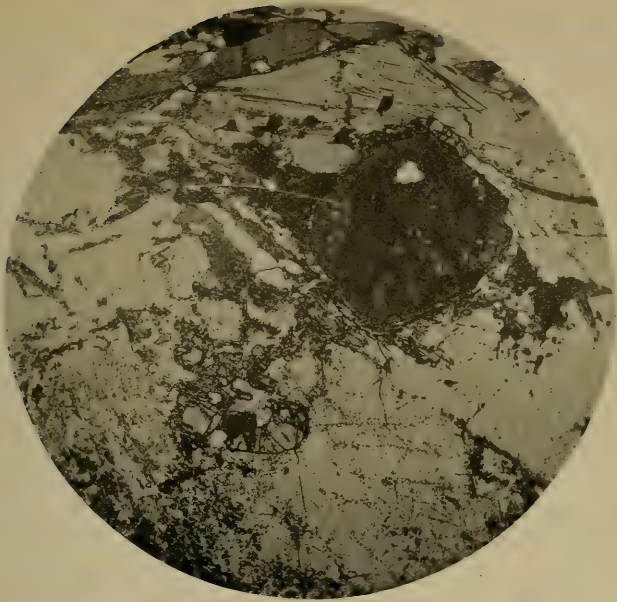


Photomicrograph of no. 332-*a*. Reservoir granite. Taken with crossed nicols, magnification about 30 diameters.

Showing large plain fresh biotites cutting and distributed through a very finely granulated feldspar and quartz field.

The principal constituent is feldspar, next in abundance biotite. The others are quartz and green hornblende and epidote.

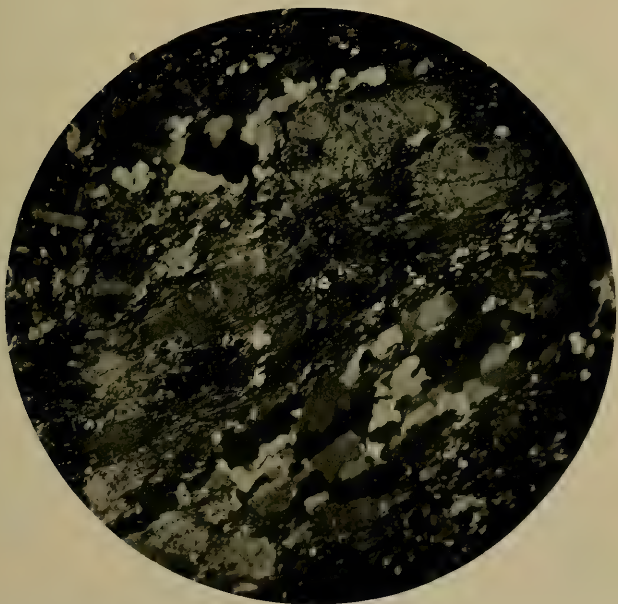
Plate 15



Photomicrograph of no. 430-*b*. Reservoir granite. Taken with plain light, magnification about 30 diameters.

Same as last slide with a different field to show other characteristic make-up. The minerals are: *a* Large areas of soda-feldspar. *b* Many small grains of quartz. *c* Many large and small flakes of biotite. *d* A very large grain of allanite. *e* A garnet area of irregular outline. *f* Very small amount of zoisite and other accessory minerals.

Plate 16



Photomicrograph of no. 16-*b*. Reservoir granite. Taken with crossed nicols, magnification about 30 diameters.

Slide shows a field with an unusually strong schistose and granular habit. The structural quality in this case is emphasized by the streaks of finer material, the granulation of some of the more brittle material and the orientation of the mica flakes developed along lines of weakness even cutting some of the other grains. The principal constituents are: *a* Soda-feldspars and orthoclase. *b* Quartz, mostly in aggregate form. *c* Biotite, mostly oriented. *d* Epidote, zoisite and small amount of other minor constituents.

The structure is the most characteristic thing about this field.

but much less so than in the Reservoir granite. The cleavage is therefore not as distinct as in the Reservoir granite.

The Mahopac granite shows in thin section a combination of the characteristics of the Reservoir and Storm King granites. It has the marked perthitic growth which is the most constant feature of the Storm King, and also the intensely pleochroic biotite. The granulated edges of the feldspar, the later simultaneous introduction or development of the quartz and biotite, and the accessory muscovite show resemblance to the Reservoir granite. These characters are considered critical and the rock is therefore judged to be essentially a facies of the Reservoir type. It may even be that this is a more fundamental or less abnormal type than the Reservoir, but in any case it seems to belong to the same invasion. The peculiar zoisite inclusions of the Reservoir granite are lacking, possibly because of the lower lime content of the country rock absorbed by the Mahopac magma. This is also shown by the feldspars which are chiefly perthite and microcline.

Megascopically the granite appears to be an intermediate type. It is a light pink gneissoid granite which looks very much like the Yonkers gneiss of the Tarrytown quadrangle. It is a more distinct field unit than the Reservoir and not so distinct as the Storm King granite.

This granite is therefore petrographically a transition variety between the Reservoir and Storm King granites rather than a clear-cut independent type, and it is therefore difficult to locate accurately. The country southeast of Peekskill Hollow creek, bounded on the south by Peekskill creek, the Peekskill granite, Osceola lake, and Lake Mahopac, has this granite as its chief intrusive. The best exposures are along the road running from Kent cliffs to Mahopac mines, especially on the fault scarp north of Mahopac mines, and also in the hill north of Peekskill in contact with the Poughquag quartzite.

The Peekskill Hollow boundary is a sharp one, as here there is an unconformity and the Cambrian quartzite is laid down on the old eroded granite surface. The contact with the Reservoir granite is not at all clear. The best evidence as to the character of the contact is shown on the Kent cliffs-Mahopac mines road at a point just off the edge of the quadrangle. Here a pink granite dike with indefinite boundaries lies in contact with the gray, granite, and little wavering stringers of pink penetrate the gray blending with it. The rocks are evidently of approximately the same age. The resemblance between the Mahopac and the Storm King granites is chiefly mineralogic and is most apparent in the microscope. (See plate 17 for microscopic appearance.)

Although it would be possible to map this granite separately, it was finally decided on the grounds of its evident close relation to the Reservoir type, to consider it simply a facies of that invasion and include these together as one map unit.

Storm King granite. The Storm King granite is a medium to coarse-grained rock, rather dark colored, slightly greenish and sometimes greasy looking, with a marked but crude gneissoid structure. The feldspars are gray or red, the quartz is gray, and there is strong black streaking of hornblende or augite. Biotite is not abundant. Garnet occurs more in the marginal portions of the mass and is probably produced by absorption of the invaded Grenville.

The quartz content varies from that proper to a normal granite to very low, so that a considerable portion of the rock approaches the composition of syenite. High quartz content and red feldspar commonly occur together. The pegmatitic phase is a distinctly red granite, very coarse-grained and not at all gneissoid, with lower ferromagnesian content than the main mass of the rock.

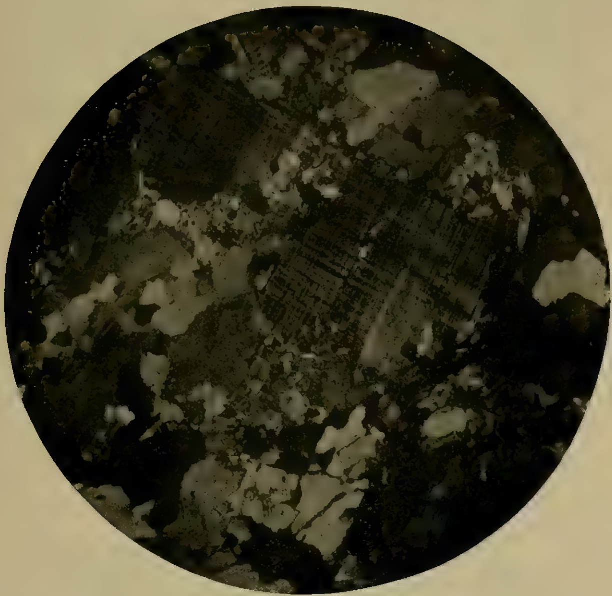
In thin section it is a coarse-grained rock with good granitoid structure. The characteristic features are (1) intense pleochroism of the biotite and hornblende which turn from green and light yellow-brown to almost black, (2) abundance of microperthitic intergrowths.

The essential minerals are quartz (in some specimens), perthite, microcline, oligoclase, biotite, hornblende, and light-brown augite in the darker varieties. The accessories are a little garnet occasionally associated with the hornblende, rather rounded zircon, apatite and magnetite. Allanite is rare. The magnetite appears in grains and also along the cleavages of augite (plates 18 and 19).

The rock is fresh with no evidence of alteration except slight sericitization of some of the feldspar, and development of chlorite small, usually not over 5 or 6 feet wide. They are the latest of the sort caused by regional deformation, but strain effects are well shown in the quartz and feldspar. Crush zones, although rare, are known in this formation. Some of them are so completely healed as to form perfectly solid rock.

Basalt, Diabase, Diorite. The basic dikes of the Highlands are small, usually not over 5 or 6 feet wide. They are the latest of the Precambrian rocks, cutting all the others, and are themselves quite

Plate 17



Photomicrograph of no. 479. Mahopac granite. Taken with crossed nicols, magnification about 30 diameters.

Taken to show a characteristic field of this type. Note particularly

a Large microcline grains

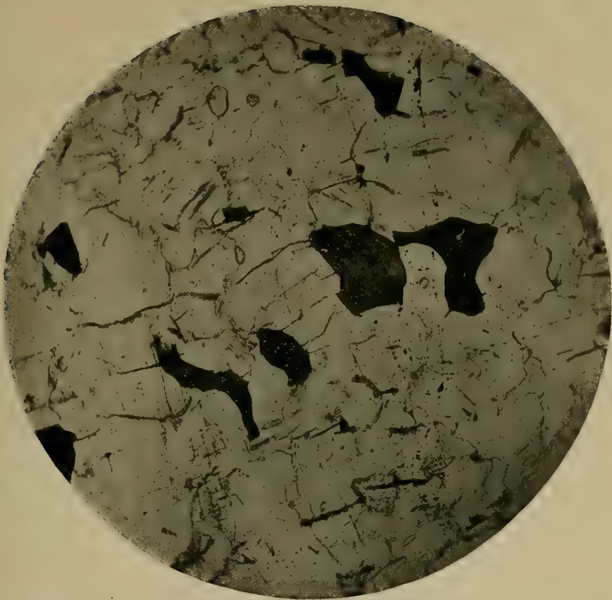
b Numerous granular aggregates of quartz

c Little biotite

d Very small amount of accessories

The rock as a whole is characterized by rather large feldspars, chiefly microline with occasional very slight perthitic development. There is little biotite and a very large amount of quartz which is distributed in grouped aggregates interstitially, and in isolated grains in lesser amount, and also in very minute amount intergrown micrographically with feldspar.

Plate 18

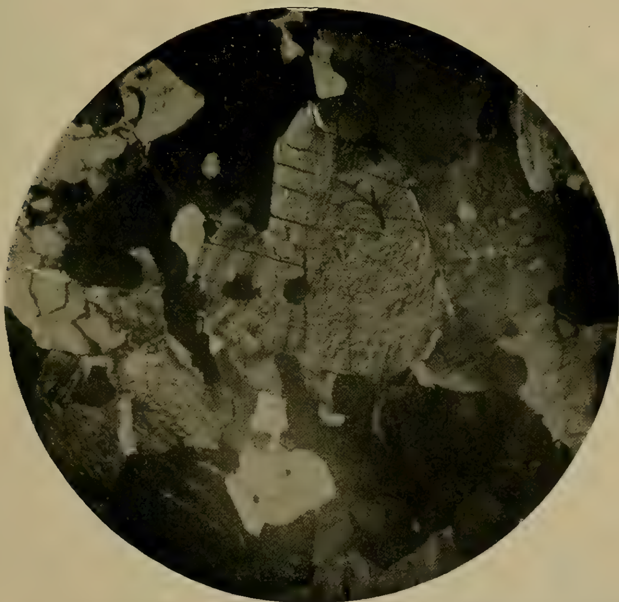


Photomicrograph of no. 187-*b*. Storm King granite. Taken with plain light, magnification about 30 diameters.

Taken to show the distribution of ferro-magnesian minerals in the rock and the development of perthitic habit.

The minerals are: Quartz (clear), perthitic feldspar, hornblende (dark rough grains), biotite (dark smooth flakes).

Plate 19



Photomicrograph of no. 187-*b*-*x*. Storm King granite. Taken with crossed nicols, magnification about 30 diameters.

A different field of the same slide as the previous one taken with crossed nicols to show better the micro-structure of the rock, especially the microperthite habit and microline and the strained condition.

The minerals are quartz, perthite, acid plagioclase, microcline, hornblende and zircon.

unmetamorphosed except locally in certain shear zones. One of the simplest and least modified of this type is no. 115 (plate 20), a basalt.

The rock weathers to a buff color. The fresh fracture shows a dense rather dark greenish gray surface, felsitic to finely crystalline with occasional fine-grained, roundish pyrite aggregates. In thin section small feldspar and olivine pseudomorphs can be seen. The olivine is completely altered to serpentine. The rock is cut by many small intersecting veinlets of zoisite and serpentine.

Many dikes also cut the Storm King granite in Breakneck ridge and the adjacent gneisses of Crows Nest and neighboring ground. The rock here is coarser and it has more nearly the habit of a diorite than of any other type. Some may have been diabasic. As a matter of fact, they show considerable variety. They cut the Storm King granite but do not cut the Cambrian quartzite in any case yet observed.

Peridotite or dunite. A curious rock which may be related to the diabases is the dunite exposed near Tompkins hill. It forms a small hillock which is cut by the road and is surrounded by gneisses or granite. The contact is drift-covered. It is a fine-grained rock, weathering buff colored. No phenocrysts can be distinguished. In thin section it is seen to be an almost pure olivine rock, with a few magnetite grains. There is slight serpentinization which gives a faint silky luster to the fractured surface. This rock (no. 57) is illustrated by a photomicrograph (plate 21).

Mixed types. Under this head are listed a few typical representatives of a very large group of rocks which are less constant in their petrography than those just described. In most cases they are judged to be either mixtures such as syntectic products, or they are impregnation effects or injection on a microscopic scale or they are extreme facies of the types just described. Perhaps some belong to units of still a different connection not prominent enough to be mapped independently. Only one in this list, however, is considered of enough independent prominence to be indicated on the map and this is the hornblende gneiss which, if there is a representative in this district at all, must be the equivalent of the Pochuck formation as described in New Jersey. All the others are included in mapping with the major units in which they are involved.

a Hornblende-plagioclase Gneiss (Pochuck). Hornblende-plagioclase or pyroxene-plagioclase representatives are common in small and scattered development or so involved with other kinds of material that they can not well be treated as a separate member. The most pronounced occurrence of this sort is in a belt beginning at Peekskill and extending in a somewhat broken way toward the northeast and again in the vicinity of Oscawana extending also somewhat brokenly toward the northeast. The most distinctly individual occurrence is at Peekskill, where a belt about 1000 feet in width lies between simple Grenville on the one side and a granite on the other.

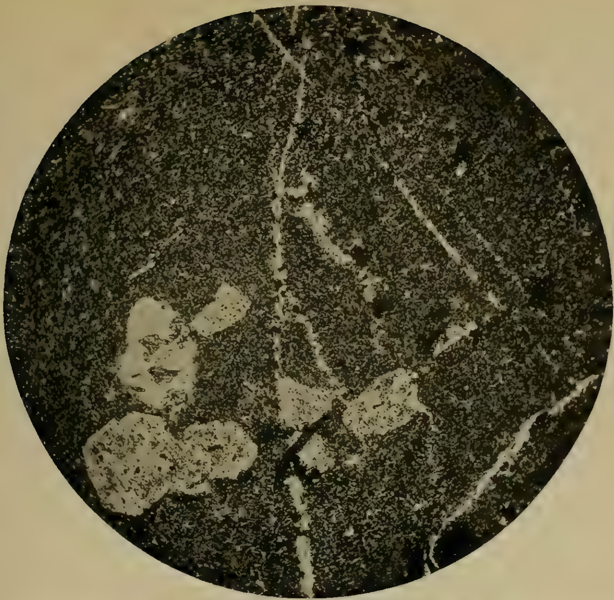
Undoubtedly these hornblendic plagioclase rocks are related to the Pochuck diorite type in origin and, wherever they can be separately mapped, they should be indicated as Pochuck gneiss. This can be done at a few places such as the belt at Peekskill extending to the northeast, but a much larger number of occurrences are on such a small scale and so intermixed with material judged to be of other sources and relations that they have not been separately mapped. This is particularly true of considerable areas toward the east side of the quadrangle where the hornblendic varieties of rock are abundantly intermixed with remnants of the Grenville. We have indicated a large area as Grenville mixed with granite but have not found a way of indicating its Pochuck intermixture in all cases.

This rock carries a large proportion of either hornblende or pyroxene or both, usually also biotite, an abundance of plagioclase and varying amounts of quartz. The accompanying photomicrographs illustrate the normal appearance. (Plates 22, 23 and 24.)

b Magnetite schist. Some of the finer grained rocks which carry magnetite in considerable portion have the general appearance of schists, but microscopically they show little foliation habit. The constituents are generally pyroxene, sometimes hornblende, abundant quartz and feldspar and magnetite. The proportions vary greatly and accessories are sometimes prominent, especially apatite. They are usually impregnation and replacement products representing a phase of igneous invasion. The general structural habit and mineral relation is shown in the accompanying photomicrographs. (Plates 25 and 26.)

c Quartzitic gneiss. Occasional occurrences of very limited extent have the hand specimen appearance of recrystallized quartzites and were at first marked so in the field. Microscopic examination shows that they are not by any means so simple and are evidently not quartzites at all. Instead they are judged to be extreme differentiation products of some injection unit high in quartz. (Plate 27.)

Plate 20

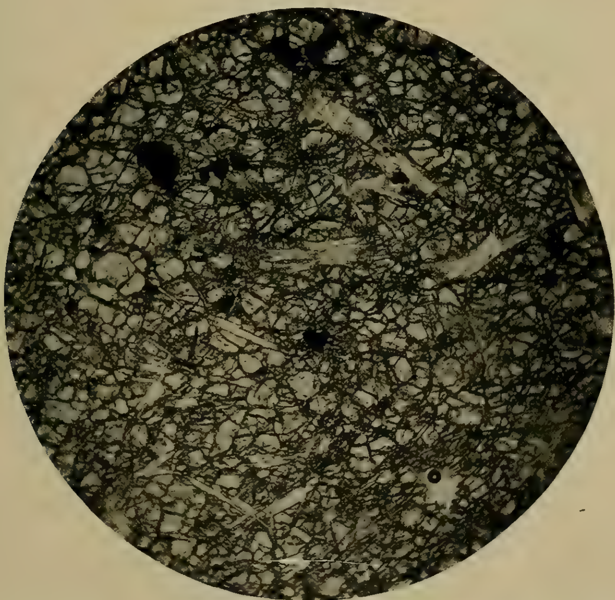


Photomicrograph of specimen no. 115. Basalt. Taken with plain light, magnification about 50 diameters.

Taken to show the fine felsitic ground mass habit of this rock with its slightly porphyritic texture and its rather numerous rehealed fractures.

The rock is not recrystallized and not sheared, but it is fractured and rehealed and somewhat altered.

Plate 21



Photomicrograph of specimen no. 57. Dunite. Taken with plain light, magnification about 30 diameters.

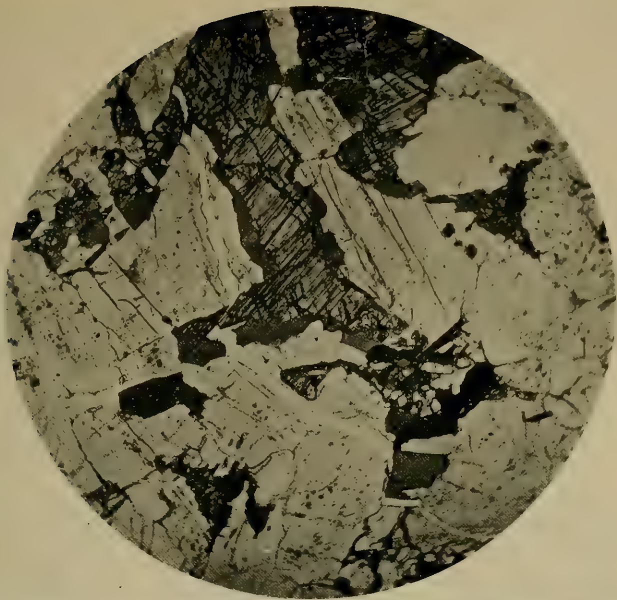
Taken to show the structure and make-up of this very unusual specimen.

1 The principal constituent is olivine

2 The flaky shreds are antigorite

3 The black spots are magnetite

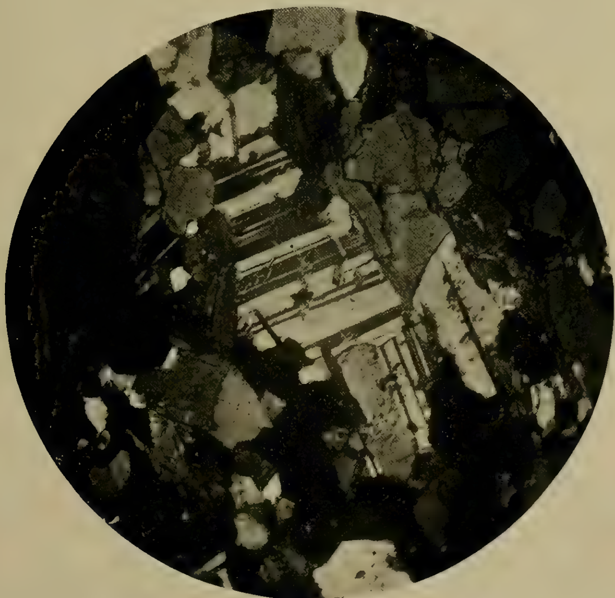
Plate 22



Photomicrograph of no. 77. A hornblende-plagioclase-gneiss (probably Grenville invaded by Pochuck diorite). Taken with plain light, magnification about 30 diameters.

Showing: *a* Pyroxene with strong green hornblende border (dark grains with cleavage). *b* Plagioclase feldspar field (light gray). *c* Biotite (smaller flakes and dark smooth mineral). *d* Magnetite (black granules). *e* Apatite (high relief small light crystals).

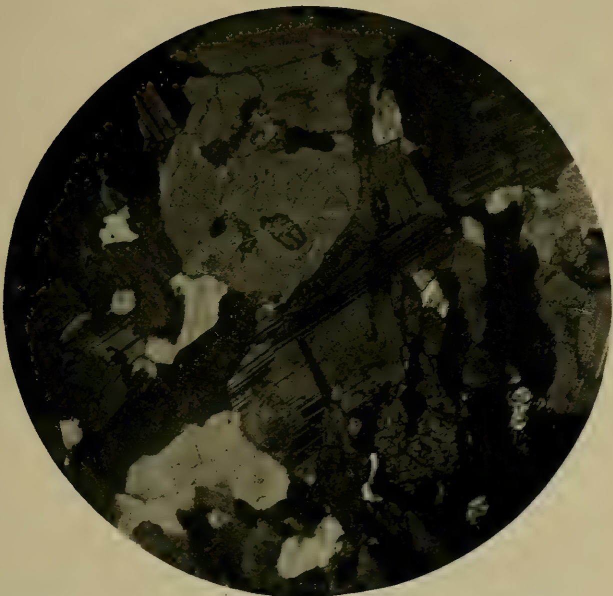
Plate 23



Photomicrograph of no. 55. Hornblende-plagioclase-gneiss (Pochuck). Taken with crossed nicols, magnification about 30 diameters.

Showing: *a* Abundant hornblende (dark and rough). *b* Abundant plagioclase (banded). *c* A little quartz (clear grains). *d* A little biotite (dark flakes).

Plate 24

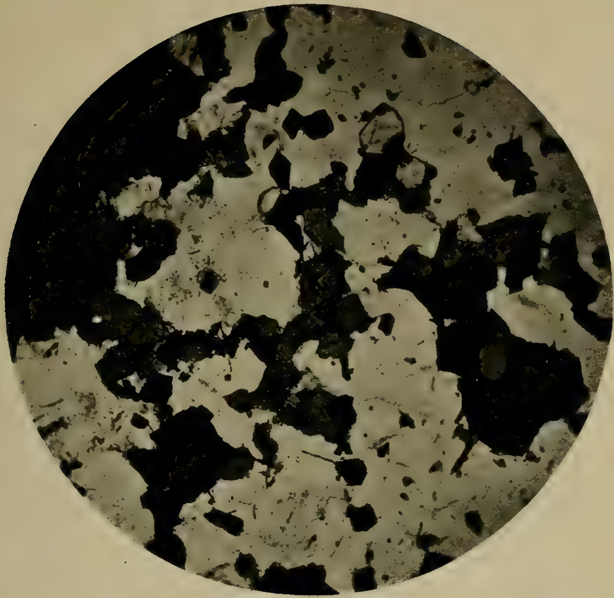


Photomicrograph of no. 306. Hornblende-plagioclase-gneiss, essentially Pochuck injection product. Taken with crossed nicols, magnification about 30 diameters.

Showing:

a Abundant plagioclase (banded)
b Abundant hornblende (coarse dark)
c Several large grains of titanite (very rough)
d A very little magnetite

Plate 25

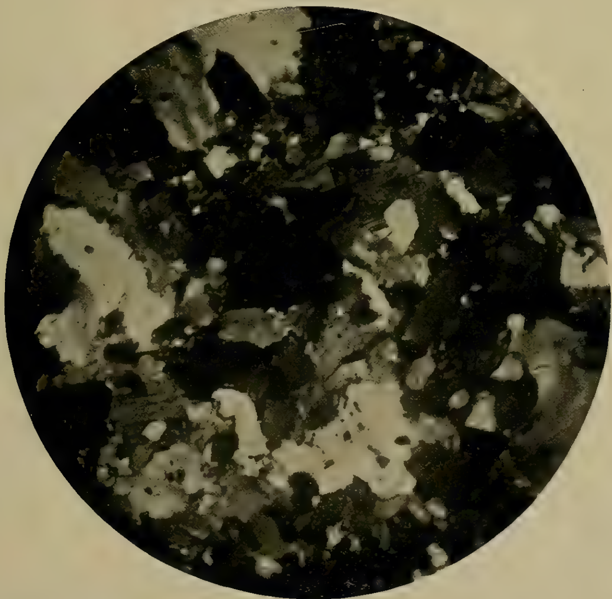


Photomicrograph of no. 373-*a*. Magnetite schist (Grenville). Taken with plain light, magnified about 30 diameters.

Taken in this light to show mineral association and structure.

a Magnetite (dead black). *b* Pyroxene (dark and rough). *c* Quartz and feldspar (clear). *d* Apatite (white stronger relief).

Plate 26

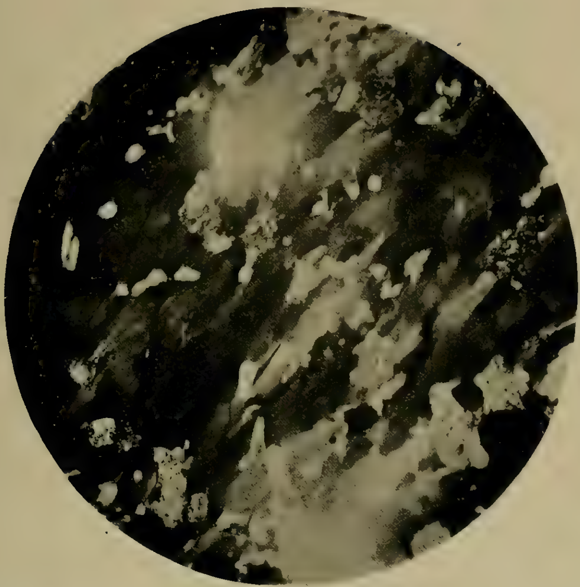


Photomicrograph of no. 373-*x*-*x*. Magnetite-schist. Taken with crossed nicols, magnification about 30 diameters.

This field shows the structure and mineral make-up of this rock.

a Quartz (clear and with strain shadows). *b* Striated feldspars (a few grains). *c* Magnetite (dead black grains). *d* Pyroxene (rough grains).

Plate 27



Photomicrograph of no. 432-*a*. Taken with crossed nicols, magnification about 25 diameters.

Showing the microstructure in this specimen. A single original quartz unit covers a large portion of the field. It includes other matters among which are grains of feldspar, separate quartz grains, biotite and black granules and the principal quartz unit is itself much strained and preserves evidence of fracturing and rehealing.

Although the hand specimen has all the usual megascopic appearance of a quartzite, it is rather plain from a microscopic examination that the material is not of such simple origin. The quartz has all the habit of vein quartz, and its tendency to include other grains and be intergrown with other units of the same quartz make one believe that it is a differentiation extreme of magmatic origin, similar to the quartz stringers described and illustrated in nos. 163 and 389.

The feldspar grains and some of the other grains included in the quartz of this specimen have the same habit as have the original rock materials noted in no. 163 and are believed to be remnants or representatives of remnants of the original rock which was invaded by this quartz.

Although the rock shows abundant deformation effects especially fracturing and rehealing, it is evident that the composition as well as the distribution of minerals favors the theory of development from a fusion or solution. It may very well be that it is not a simple injection effect and this is indeed suggested by the presence of garnet in rather prominent development (plate 28). The occurrence of areas of quartz acting essentially as a host in poikilitic structural habit with the other constituents adds also to the certainty that it is not at all a metamorphosed quartzite in origin, but it is believed that there are remains of an older rock and that some of the minerals in it, such as garnet, are essentially syntectic products (plate 29).

d Injection gneisses. The writers interpret many of the mixed banded gneisses as injection effects. In the coarser and more sharply defined occurrences there is no considerable doubt about this being their origin, but in the fine structured varieties where the different parts are not so well defined it is believed to be quite impossible to distinguish material of different sources.

It is certain, however, that injection on a fine scale is quite as important in the gneisses of the Highlands as the coarse types, and this fine injection process doubtless gives much of the variety to the more obscure gneisses. If the injection habit is maintained distinctly in these five types one ought to see it occasionally in the microscope. As a matter of fact it is sometimes found very sharply defined on a microscopic scale. No. 163 has furnished several good photomicrographs for illustration (plates 30, 31 and 32).

e Impregnation gneiss. A more intimate mixture than the type just described may be called an impregnation gneiss. Typically it ought to contain grains belonging to the original rock intimately associated with grains of introduced origin connected with magmatic invasion. Although the conclusion is fully justified that such rocks occur in considerable abundance in this district, the finding of suitable illustration material is difficult and in even the best occurrences it is doubtful whether one could with certainty distinguish between the two sets of components. It has seemed to us in the examination of this field that the Canada Hill type of granite succeeds better in accomplishing such impregnation than any other type although the Reservoir granite is a close second and the dioritic magma, represented by the hornblende plagioclase gneiss or Pochuck, has intimate penetrative habit also. One specimen taken from the Grenville gneiss belt in proximity to the typical Canada Hill granite shows sets of constituents that are believed to represent these two different sources. In this case the original is judged to be a representative of the Grenville series and the invading material is judged to be the Canada Hill granite. (Photomicrograph of no. 395 shows a typical field.) The invading magma is represented chiefly by microcline and the original rock material by the other more irregularly disturbed and confused looking grains. The older minerals have multitudes of inclusions and modification products whereas the invading minerals are perfectly fresh (plate 33).

Metamorphics of doubtful age. Three formations are classified under this head in preference to connecting them more definitely in the historical sequence. They form a series including: (a) the Manhattan schist, (b) Inwood limestone, (c) Lowerre quartzite.

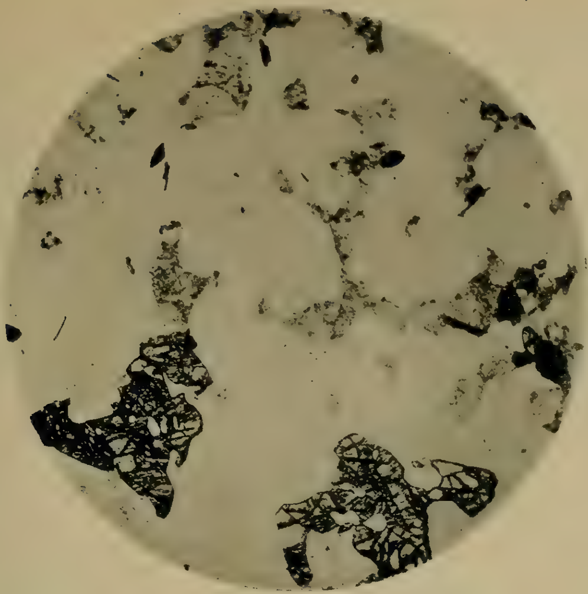
The first two are largely developed in this quadrangle and the last one very erratically or not at all. These formations can be traced from New York City, which is the type locality, northward to the Highlands into the southeast quarter of this quadrangle. Here they have a typical petrographic development, but their prominence in the field is much obscured by the heavy drift cover. The Cortlandt series also cuts into the area which would otherwise be occupied by these formations and eliminates about 20 square miles.

No rocks of this type are found west of or northwest of Peekskill and the abrupt termination of so great a series with no remnants of similar habit beyond this border is one of the striking facts, and introduces one of the largest unsolved structural problems of the region. It has been suggested that this series is the equivalent of the Hudson River-Wappinger-Poughquag series, but the authors feel that this has not been proved. In the lack of a better classification of age relations and, because particularly of the very strikingly different petrographic habit of these formations as compared with the other series they prefer to treat them in a separate class and are willing to consider their age doubtful.

a Manhattan schist. The Manhattan formation is everywhere a schist of very complete recrystallization. In structural make-up it is strongly foliated and of dominantly micaceous composition. In some cases it is almost wholly mica with a light pearly mica predominating, but it varies from this to a strongly quartzose rock, essentially a quartz-mica-schist and in some of these cases black mica is fairly prominent. Pearly mica, however, is the most characteristic single mineral.

At occasional points strongly hornblendic schists are developed from former igneous intrusions of essentially diabasic composition, but these are not largely developed in exposures of this quadrangle.

Plate 28

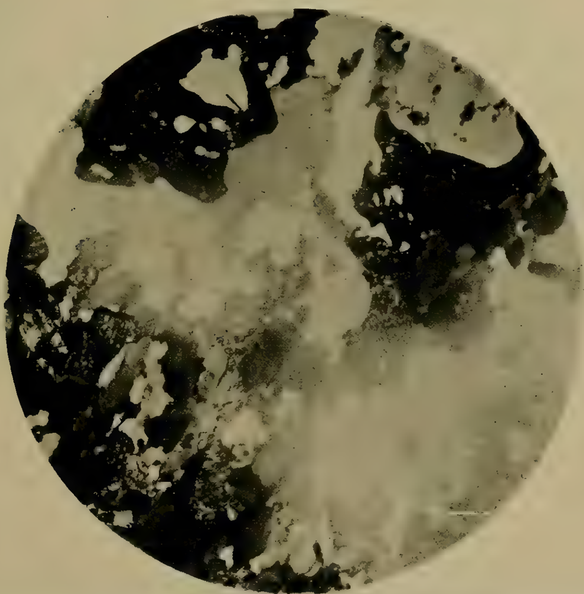


Photomicrograph of no. 432-*b*. Taken with plain light, magnification about 25 diameters.

Taken for the purpose of showing a typical distribution of feldspathic and other material with the quartz of this specimen. Minerals present are: *a* Garnet, two large rough irregular grains. *b* Orthoclase, slightly altered (gray smooth). *c* Biotite, three or four small flakes at one side of the field (smooth dark flakes). *d* A crystal of zircon (rough) associated with the biotite. *e* A few black metallic grains (dead black).

The rest of the field is quartz which is believed to be the youngest constituent and forms the principal mass of the whole specimen. The other rather isolated grains are believed to be remnants of a previously existing rock which has been invaded and replaced and largely absorbed.

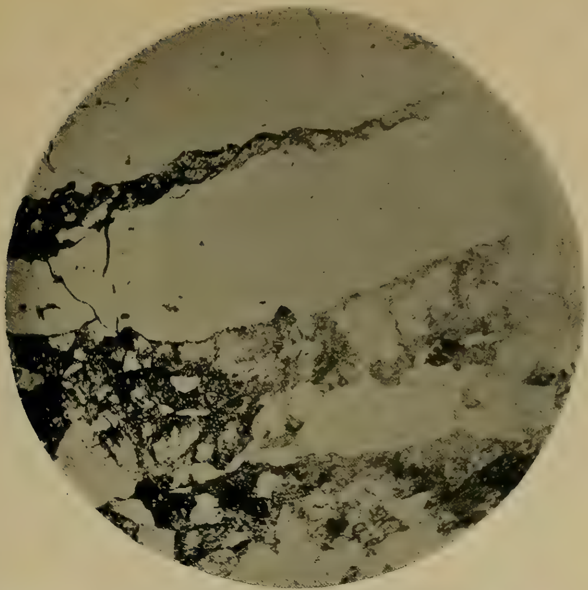
Plate 29



Photomicrograph of no. 432-*c*. Taken with crossed nicols, magnification about 25 diameters.

This is the same field as 432-*b*, taken for the purpose of showing the structural relations, especially the complex interlocking of the quartz.

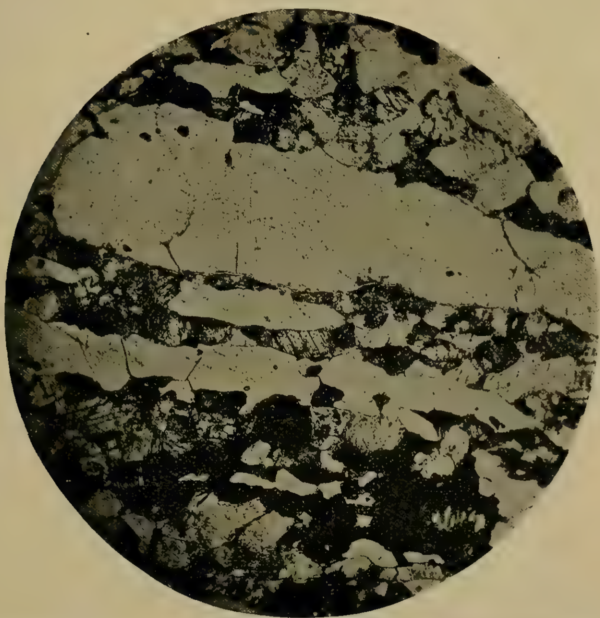
Plate 30



Photomicrograph of no. 163-*a*. Taken with plain light, magnification about 25 diameters. Taken particularly to show the intimate penetration of injection matters, especially quartz.

The grayish portion of the field is chiefly made up of slightly altered feldspar and associated quartz. These are cut by later quartz which appears in clear bands which, if followed farther in the slide, can be seen to widen or narrow and sometimes pinch out entirely as they extend into the older material.

Plate 31



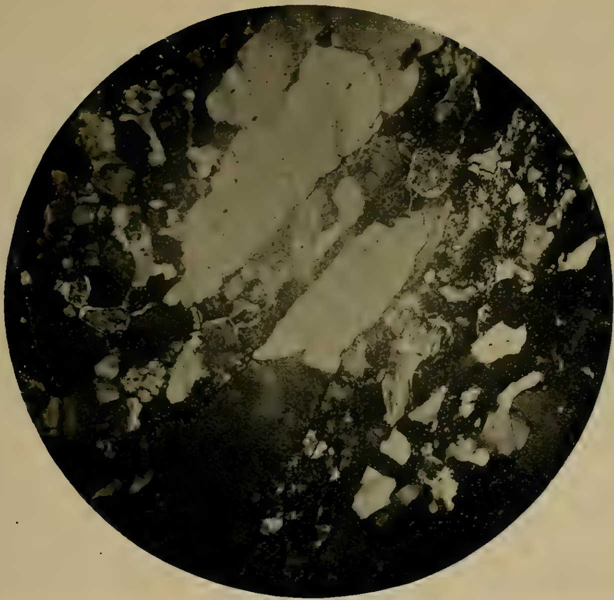
Photomicrograph of no. 163-*b*. Taken with plain light, magnification about 25 diameters. A second photomicrograph taken from the same slide as no. 163-*a*.

The field shows a similar habit to 163-*a* in that the older rock material is represented by the grayish bands and the newly introduced quartz by the clear colorless bands.

The older rock material is represented by slightly altered orthoclase and microline, by a little quartz in small grains, and by pseudomorphs made up of secondary chloritic aggregates.

Some of these, no doubt, represent former ferro-magnesian minerals and are very dark. The subsequently injected matter is quartz which cuts through and into the older material in tongue-like stringers and narrow bands. Three of these are distinctly represented in this field, the central and widest one terminating within the bounds of this particular field. One of the others is a very narrow and somewhat broken looking stringer and at the opposite side of the field a third band wedges out to almost nothing.

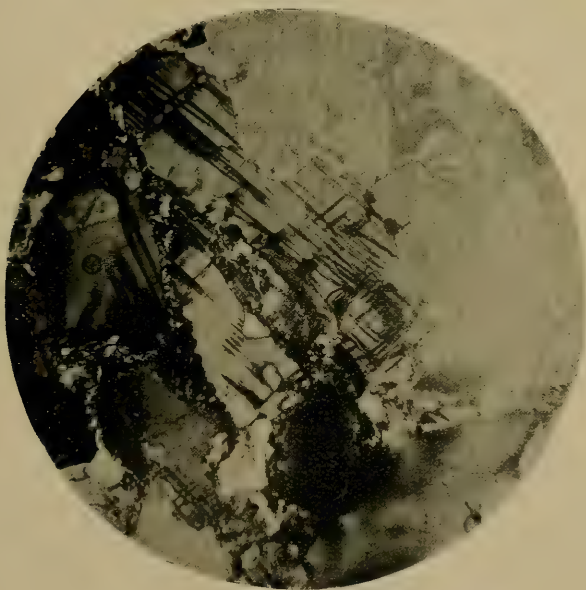
Plate 32



Another photomicrograph of no. 163. Taken with crossed nicols, magnification about 25 diameters.

This method shows better the mineral habit of the rock with its coarse injection quartz and its much finer feldspathic original content.

Plate 33



Photomicrograph of no. 395. Grenville gneiss. Taken with crossed nicols, magnification about 45 diameters.

Taken to show the mixed nature of a typical gneiss. This one is judged to be an injection or impregnation gneiss in which the microcline can be clearly seen to cut or penetrate the other feldspathic constituents. The microcline has a stringerlike distribution in this field and is perfectly fresh, whereas the immediately adjacent orthoclase feldspar is much affected by sericitic alteration.

The constituents are in part of Canada Hill type and in part are judged to be of Grenville source.

In places also pegmatitic injection effects are very prominent indeed and the rock is charged more or less with feldspathic and quartzose matters of this origin, so that it is much more complex in composition at these places than is normal for the simple metamorphosed rock.

More rarely other minerals are prominent, such as sillimanite, graphite, carbonate, sulphide, feldspar, tourmaline and garnet, but these are not by any means uniform and some are comparatively rare. The most widely distributed of this lot of constituents probably is garnet, which seems to be a regional metamorphic in origin. It is very generally and abundantly distributed in this formation.

The rock is always foliated and sometimes streaked, but never banded. It is in many places crumpled in a very complex way, but this is not a universal effect. It is more likely to be streaked in connection with pegmatitic development and it is very seldom indeed that one can find any evidence whatever of original bedding, although the general structural trend and the limestone contact as well as certain sill-like meta diabases (hornblende schist bands) give some general idea of the formational attitude.

The average microscopic appearance is illustrated by photomicrographs (plates 34, 35 and 36).

Analysis of Manhattan Schist

Composite of five specimens from the borders of the Cortlandt series, representing the different types. One is chiefly garnet, quartz and mica; the others carry considerable feldspar, along with the quartz and mica.

		Mode	*Recast*	
SiO_2	57.94			
Al_2O_3	21.70	Qtz.	19.20	
Fe_2O_3	1.57	Or.	5.56	
FeO	5.90	Ab.	14.67	Plag. = Alb.
MgO	2.49	An.	2.50	
CaO	.50	Muscov.	38.01	
Na_2O	1.74	Biot.	14.86	
K_2O	4.68	Mgt.	.70	
H_2O+	2.17	Ilmen.	1.85	
H_2O-	.29			
P_2O_5	tr		97.35	
TiO_2	1.01			
MnO	.19			
	100.18			

Analysis and recast by G. Sherburn Rogers.

The distribution of the K_2O and H_2O is entirely arbitrary. No account is taken of the garnet in this recast.

b Inwood limestone. The Inwood limestone outcrops in a belt about five miles long, striking approximately East-West, in the southeast part of the quadrangle in Yorktown. The best exposures are at Amawalk and at the cross roads east of Mohansic lake. The limestone is comparatively nonresistant to weathering so that outcrops are few and inconspicuous. Open valleys tend to develop on this formation.

It is a white limestone stained yellowish near the surface. The fresh fracture glistens with shiny mica scales. It is of medium coarseness with rounded or equant grains and crumbles readily in the hand to a rather coarse sand.

In thin section it is a coarse-grained limestone carrying muscovite or phlogopite and a little tremolite. The calcite grains are rather simple in form, not well interlocked. They show the effect of dynamic stress in the twinning bands and the well-defined cleavage cracks. The mica is a later development. There is no good evidence here of contact metamorphism.

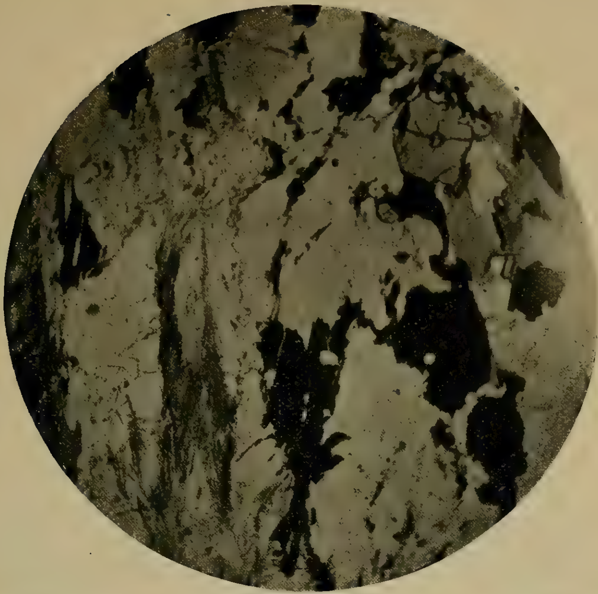
The Cambro-Ordovician sediments. Two patches of Cambro-Ordivician sediments are represented on this map; one on the north margin of the Highlands at the foot of Breakneck ridge where a part of the lowland of the great valley comes within the boundaries of this sheet; the other place is along Peekskill Hollow creek. The types of sediments are represented by quartzites, limestones, shales, slates, phyllites and graywackes, belonging to three distinct formations as follows:

a Poughquag quartzite. This rock is developed in beds approximating 600 feet in thickness. It is in general an almost pure quartzite. It has been completely indurated and to some degree recrystallized. Certain beds have an appreciable feldspathic content and others have a carbonate intermixture in considerable amount. It has enough iron also to give it a little color so that chemically it is not quite such pure silica as the appearance of the rock would at first lead one to believe.

There are no unusual petrographic features or characteristics introducing special questions or uncertainties of interpretation.

b The Wappinger limestone. This formation is represented by a finely crystalline limestone. The beds lie immediately above the Poughquag in conformable relation and are developed to a thickness of approximately 1000 feet. In no place in this district, however, is the thickness determinable, except as an interpretation from the

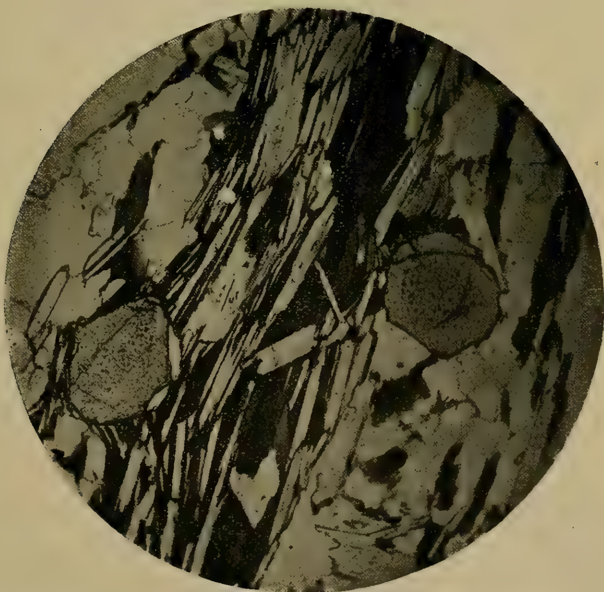
Plate 34



Photomicrograph of no. 499. Manhattan schist. Taken with plain light, magnification about 25 diameters.

Showing: *a* Foliate structure. *b* Quartz (clear grains) abundant. *c* Biotite (dark smooth flakes). *d* Fibrolite (fibers and needles). *e* Pyrite (black large grains). *f* Garnet (rough gray grains). *g* Magnetite (small black specks).

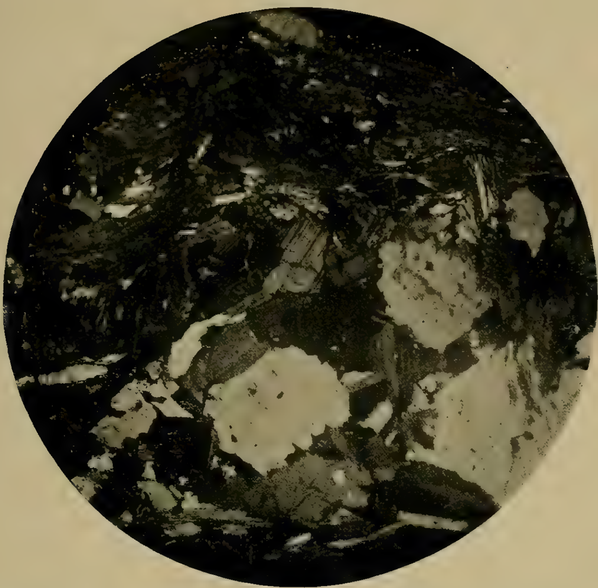
Plate 35



Photomicrograph of no. 1. A typical specimen of Manhattan schist. Taken with plain light, magnification about 30 diameters.

Showing: *a* Strong schistose structure. *b* Mineral make-up including (1) quartz (clear grains), (2) muscovite (clear plates), (3) biotite (dark plates), (4) garnet (coarse rough crystals), (5) iron oxide, a little (black specks).

Plate 36



Photomicrograph of no. 492-*b*. An injected or impregnated variety of Manhattan schist. Taken with crossed nicols, magnification about 25 diameters.

Showing very irregularly distributed constituents including:

a Abundant biotite (foliated)

b Abundant plagioclase feldspar (banded grains)

c Quartz (clear grains)

d Fibrolite (rods)

e A very little magnetite

folds in Peekskill Hollow. The rock is not so coarsely crystallized as the Inwood and older limestones, but is recrystallized sufficiently to destroy traces of such organic remains as may have been present. As a result, no evidence from that source is available from this material. There are no special peculiarities.

The rock is quite granular where it is affected by decay or leaching, such, for example, as was encountered in the borings of Peekskill hollow, but on exposed surfaces deformation effects such as crushing and rehealing are brought out prominently by differential weathering. The bedding, except in very badly deformed zones, is distinct and easily followed, and as far as observed, there is no contact metamorphism produced in this type.

c Hudson River formation. The Hudson River formation is very variable in quality of beds represented. Some of them are very fine grained and were originally muds or silts, which by regional metamorphism have developed into slates and phyllites. There are no undisturbed beds either of this or any of the other formations and on this account simple shales are not to be found at all.

Some of the beds were originally lithic sandstones which have become quartzites and graywackes and shaly sandstones. The petrographic variety is as great as the whole range of such mixtures could be. The principal types are represented by the following:

(1) *A graywacke.* This is a greenish rock of granular habit having all the general appearance of the so-called bluestones of the Catskills. This is not the formation, however, to which the true bluestones belong, although it has furnished similar structural material for local use.

The chief interest attaches to petrographic habit and composition which show that the rock is made up largely of fragments of rock instead of mineral fragments. Many varieties of rock are represented in these constituent grains, the commonest being fragments of rock of types not very unlike some of the beds of the Hudson River formation itself; that is, slaty and gritty and granular rocks of moderately metamorphosed condition. Fragments of dolomite are sometimes seen also and of course simple grains as well.

The fact that the formation is made up largely of matters that represent older formations of very much the same type, formations which must have been metamorphosed at the time that the Hudson River formation was being accumulated, is very significant. It is in this respect similar to the true bluestones of the Catskills which are made up chiefly of lithic grains believed to represent in that case derivation from the Hudson River formation and its associates, which were at that time exposed to erosion by folding and uplift.

It is an interesting fact, therefore, that the Hudson River formation shows similar derivation from something which preceded it. Rock like the Hudson River graywacke could not have been made from such a series as the Pre-cambrian basement on which it now rests, represented by the gneisses and granites of the Highlands. It could, of course, have been made from the simpler metamorphosed sediments such as might be assumed to represent portions of Grenville or portions of the Manhattan-Inwood series. This is a case, therefore, in which petrographic interpretation of the character of the material constituting a rock has a decided bearing on its possible relation to other formations in the region.

(2) *Phyllites and slates.* The simpler slates require no further attention in this discussion. The most modified of the Hudson River formation representatives in this district are the phyllites of Peekskill hollow. This rock is recrystallized, sheared, somewhat crumpled, and perhaps granulated also in certain parts. It has minute mica flakes abundantly developed which give the phyllitic habit to the rock. As a matter of fact, however, quartz is much more abundant in the rock than the hand specimen would suggest and it has essentially a quartz-mica composition. In no place, however, is it coarse grained. This is of particular significance in view of the fact that the Manhattan schist formation with which this phyllite is sometimes correlated and which occurs at Peekskill only about a mile distant is very strongly foliated and very coarsely and completely recrystallized.

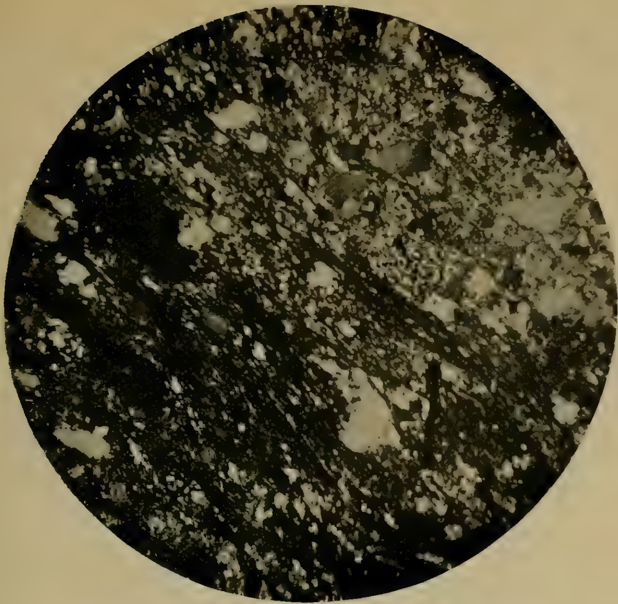
The phyllite carries many pyrite crystals or pseudomorphs after pyrite and occasional black carbonaceous looking material but other identifiable constituents are rare (see accompanying photomicrographs of this type, plates 37, 38, 39 and 40).

The Younger Igneous Rocks

Peekskill granite. The Peekskill granite is a small irregular-shaped mass about 3 miles long and 2 miles wide with its longer axis running N of E, lying east of Peekskill. It is well exposed in two quarries, one on the Crompond Road about 4 miles east of Peekskill and the other a little east of the road running south from Mohegan lake. The latter occurrence is the site of a quarry. The product is known in the trade as Mohegan granite.

It has an igneous contact with the gneisses and schists, cutting them irregularly and sending pegmatites out into them. None of its

Plate 37



Photomicrograph of no. 47. Annsville phyllite. Taken with crossed nicols, magnification about 25 diameters.

Taken to show one of the more granular varieties of this phyllite. Note

a The numerous large quartz grains

b The general phyllitic habit of the rest of the field

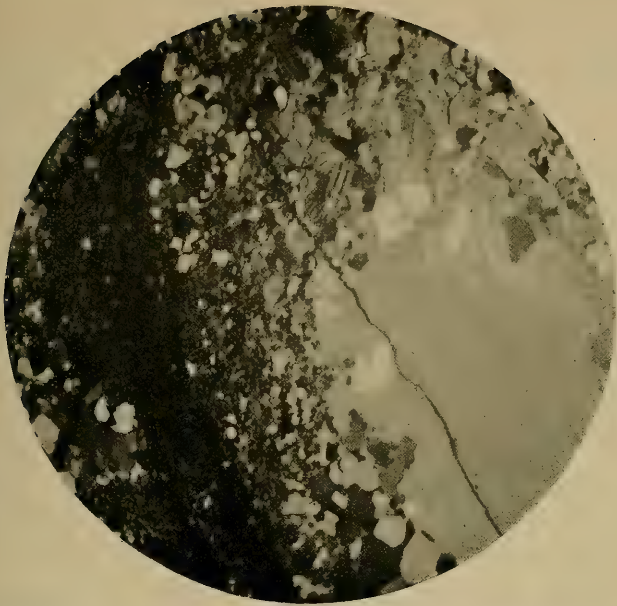
The important constituents are quartz and mica. Other matters are of small consequence.

Plate 38

Photomicrograph of no. 158. Annsville phyllite. Taken with crossed nicols, magnification about 25 diameters.

This specimen shows the typical phyllitic structure and the composition which is almost wholly quartz granules and mica flakes.

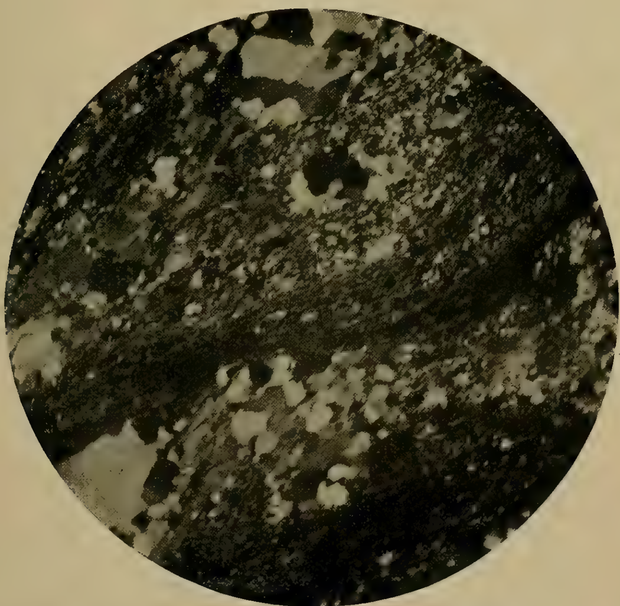
Plate 39



Photomicrograph of no. 24. Annsville phyllite. Taken with crossed nicols, magnification about 25 diameters.

Showing the typical structural quality of this rock and its principal make-up. The chief features are: *a* Very bunched distribution of granular aggregate quartz (clear). *b* Very minute flaky mica giving a streaked structure. *c* Presence of considerable carbonate.

Plate 40



Photomicrograph of no. 24-*a*. Annsville phyllite. Taken with crossed nicols, magnification about 30 diameters.

A different field in the same thin section. Showing the nature of the spotted varieties of this rock. *a* Quartz (clear) showing tendency to granulation of large grain. *b* Mica (large shreds). *c* Carbonate (rough grains).

boundaries is faulted. It has no physiographic expression, as in the Highlands all rocks have so nearly the same hardness that physiographic features are usually the result of faulting and physical condition rather than of original petrographic quality.

The rock is a light gray, medium to coarse-grained, acid granite composed of quartz, white feldspar, striated and nonstriated, muscovite and biotite. The mica is not abundant and shows no signs of orientation.

In thin section it is a coarse-grained rock of granitoid structure. The essential minerals are quartz, microcline, albite, orthorclase and muscovite, with accessory biotite and epidote. The quartz and microcline were the last minerals to form and the microcline contains cores of the other feldspars. The epidote is a primary mineral and is intergrown with the biotite and muscovite. The rock is fresh except for slight kaolinization of the albite and bleaching of the biotite, and it shows no signs of dynamic stress beyond an occasional strained quartz grain or bent mica plate.

Analysis 6847 Granite—Cornell dam (Peekskill granite)

	Norm.		Or.	Ab.	An.	C.	Mgt.	Hyp.	Q.
SiO_2....	73.54	1225	144	480	60	....	....	8	533
Al_2O_3....	15.20	149	24	80	30	15	....	....	.....
Fe_2O_3....	.50	3	....	....	....	....	3	....	.....
FeO.....	.81	11	....	....	....	....	3	8	.....
MgO....	.03	0	....	....	....	....	....	....	.....
CaO.....	1.69	30	....	....	30	....	....	....	.....
Na_2O....	4.99	80	....	80	....	....	....	....	.....
K_2O.....	2.31	24	24	....	....	....	....	....	.....

Q 533 x 60 = 31.98

F { Or 24 x 556 = 13.34
Ab. 80 x 524 = 41.92
An. 30 x 278 = 8.34 }

Corundum 15 x 102 = 1.53

Salic.......97.11

Mgt. 3 x 232 = .70
Hyp. 8 x 132 = 1.06

Femic...1.76

$$\frac{\text{Sal.}}{\text{Fem.}} > \frac{7}{1} = \text{I} \quad \text{Persalane}$$

$$\frac{Q}{F} = \frac{32}{64} < \frac{3}{5} > \frac{1}{7} = \text{Brittanaire}$$

$$\frac{Na_2O+K_2O}{CaO} = \frac{104}{30} < \frac{7}{1} > \frac{5}{3} = \text{Toscanase}$$

Lassenose (I .4.2.4.)

$$\frac{K_2O}{Na_2O} = \frac{24}{80} = < \frac{3}{5} > \frac{1}{7} = \text{Lassenose}$$

	Mode
Qtz.	32.94
Or.	11.12
Ab.	41.92
An.	8.34
Mgt.	.43
Ileminite.	.15
Biot.	3.02
Extra Al_2O. . . .	1.53

Biotite

a $3\,H_2O.\ \ Fe_2O_3.4\,SiO_2$
$4\,K_2O\ .\ 4\,Al_2O_3\ .\ 8\,SiO_2$
$8\,FeO\ .\ \ \ \ 4\,SiO_2$

Plagioclase = $Ab_5\,An_1$ = Oligoclase

Analysis and recast by G. Sherburne Rogers

Analysis 6945 **Mohegan granite**

	Norm.		Or.	Ab.	An.	Cor.	Mgt.	Hyp.	Q.
SiO_2.	73.32	1.221	234	414	48	. . . .	. . . .	17	508
Al_2O_3. . . .	15.01	147	39	69	24	15	. . . .	. . . .	. . . . .
Fe_2O_3. . . .	.47	3	. . . .	. . . .	. . . .	. . . .	3	. . . .	. . . . .
FeO.	1.19	17	. . . .	. . . .	. . . .	. . . .	3	14	. . . . .
MgO. . . .	.15	3	. . . .	. . . .	. . . .	. . . .	. . . .	3	. . . . .
CaO.	1.35	24	. . . .	. . . .	24	. . . .	. . . .	. . . .	. . . . .
Na_2O. . . .	4.27	69	. . . .	69	. . . .	. . . .	. . . .	. . . .	. . . . .
K_2O.	3.72	39	39	. . . .	. . . .	. . . .	. . . .	. . . .	. . . . .

Q	Quartz	= 30.48
F	Orth.	= 21.68
	Albite	= 36.16
	Anorthite	= 66.67
C	Corundum	= 1.53
	Salic	96.52

M	Magnetite	.70
P.	Hypersthene	2.15
	Femic	2.85

$$\frac{Sal}{Fem} = \frac{96}{e} = > \frac{7}{1} = \text{I Persalane}$$

$$\frac{Q}{F} = \frac{30.5}{64.6} \text{ or } < \frac{3}{5} > \frac{1}{7} = 4 \text{ Brittanaine}$$

$$\frac{Na_2O+K_2O}{CaO} = \frac{108}{24} \text{ or } < \frac{7}{1} > \frac{5}{3} = 2.\ \text{Toscanase}$$

$$\frac{K_2O}{Na_2O} = \frac{39}{69} \text{ or } < \frac{3}{5} > \frac{1}{7} = 4.\ \text{Lassenase}$$

Lassenose (symbol 1.4.2.4)
Near Toscanose

Analysis and recast by G. Sherburne Rogers.

Cortlandt series. The geology of the Cortlandt series has been worked out in considerable detail by G. S. Rogers.[16]

[16] Geology of the Cortlandt Series and Its Emery Deposits. Rogers, G. Sherburne, Annals, N. Y. Acad. Sci., v. 21. 1911.

The following abstract from Roger's paper gives the main results of his investigation.

The Cortlandt series of basic, igneous rocks lies in Cortlandt township south of Peekskill. It covers an area of 25 to 30 square miles. Smaller outcrops of similar rock have been found in New Jersey and at two places in western Connecticut. Stony Point on the west side of the Hudson is made up also of these rocks.

The series cuts the Cambrian limestones, but not the Triassic sandstones at Stony Point. It is therefore Postcambrian and pre-Triassic and from the absence of metamorphism the author concludes that it is post-Ordovician, but pre-Permian.

The main mass of the rocks is norite, but "examples of nearly every group from pegmatite to peridotite have been found with local developments of very peculiar and abnormal rocks."

The basic rocks are difficult to distinguish in the field as they are all dark pink or gray. The rock types described in detail are syenite, sodalite syenite, diorite, gabbro, norite, biotite-norite, biotite-augite-norite, quartz-norite, augite-norite, hornblende-norite, biotite-hornblende-norite, olive-augite-norite, hornblendite, pryoxenite, hornblende-pyroxenite, olivine-pyroxenite, peridotite, and the dike rocks, aplite, pegmatite, dacite porphyry, dioritic and gabbroic dikes, hornblendite and serpentine (peridotite). Six of these rocks are of importance areally and are described below.

Diorite. The diorites grade from pure mica-bearing to pure hornblende-bearing rocks. The brown hornblende-diorites grade into the norites, the green hornblende-diorites into the biotite-diorites. They are generally of medium grain, but with abrupt changes of texture although not of composition. Orthoclase is often present with the plagioclase, which may be oligoclase to andesine. The hornblende is usually in poorly defined grains of green color with inclusions of ilmenite. Occasional primary quartz and epidote are found. Apatite and garnet are occasionally abundant. Strain effects are found occasionally in wavy extinction of quartz, granulated feldspar and bent biotite.

Biotite-norite, biotite-augite norite, and hornblende-norite. Biotite-augite-norite is the most important of the norites. It is medium grained and dark pink or dark gray. It seldom shows metamorphism. The plagioclase is usually andesine which obtains its pink color from a fine hematitic dust, but may be labradorite in the darker rocks. Orthoclase may be present up to one-third the amount of feldspar. Hypersthene, biotite and green augite are the other essential minerals. Apatite, ilmenite, pyrite and pyrrhotite occur as accessories. This rock with decrease of augite becomes the biotite-norite, and with occurrence of brown hornblende and decrease of biotite and augite becomes the hornblende norite. Hypersthene is the chief constituent of all the norites. It occurs in stout, rounded prisms of different degrees of pleochroism. Oriented ilmenite inclusions are common. The alteration is usually to serpentine, but occasionally uralite forms.

Olivine-pyroxenite. This rock is made of augite or hypersthene with varying amount of olivine. When the percentage of olivine is large, the rock disintegrates easily into a coarse red sand. The topography of this region shows numerous rounded hillocks.

The proportions of pyroxenes vary; almost pure olivine-augite and olivine-hypersthene rocks are known and basaltic hornblende is a fairly constant component. The olivine makes up usually one-fifth to one-third of the rock. It is colorless, but contains magnetite inclusions. It is nearly always somewhat altered to serpentine.

The contact rocks have been described in detail by Williams.[17] Staurolite, sillimanite, cyanite, and garnet, biotite and magnetite are typical of the contact with the Manhattan schist. At the limestone contact are pale green amphibole and pyroxene with rarer titanite, zoisite and scapolite.

Inclusions of schist, limestone and gneiss in the igneous rock are common. The inclusions show more or less effect of absorption by the igneous magma.

The series as a whole shows little evidence of dynamic metamorphism except around the borders of inclusions, but there is a banded gneissoid structure which is believed to be original and proof of magmatic differentiation. " It appears that we have a fairly complete and very intimate complex. . . . In some places the complexity of the mass is bewildering, while again we may have several miles of a fairly uniform rock. . . . An infinite number of species might be differentiated within this small area of 25 miles " (p. 57). " The various differentiations of the norite magma are most centrally located; they are flanked on both sides by pyroxenites and between the norites and the western area of pyroxenites lies a diorite area. . . ."

" The most basic members at least grade into one another in many cases, while at times sharp contacts may be found. The analyses of the more important types indicate an unmistakable

[17] Amer. Jour. Sci. (3), 36:254. 1888.

serial relationship. It is probable that the latter (the pyroxenites) were intruded first, followed closely by the norites so that sometimes these varieties are found banded together in flowlike masses. The diorites must have come next."

STRUCTURAL GEOLOGY

(Larger structural features)

The larger structural features represented in the district are of enough variety and complexity of origin to warrant discussion under a separate head. These features may be grouped as follows:

1 Internal structures of formations, especially those with igneous control or history.
2 Form represented by the individual units shown on the map.
3 Tectonic features or deformation structures.
4 Metamorphic structures.

Internal Structure Detail

The larger units belonging to the Precambrian all show a variety of structural detail, the chief of which is a streakedness grading into clear-cut banding on one side and into massive habit on the other. This has already been referred to in its genetic bearing in connection with petrogenesis. It is sufficient in this present connection to emphasize the prominence of this feature, which characterizes practically all the older units. It is a structure which is of particular prominence in those belts where the Grenville sediments are more or less in evidence, but is not by any means confined to the Grenville limits. As already pointed out, the origin of much of the structure is due to an actual mixing of types, so that a gradational boundary rather than a sharp line division ought to be expected and is commonly found.

In spite of this fact, there are reasonably clearly defined large field units, and their internal structural detail, however complicated, must be considered of minor significance.

In addition to the streakedness and the banding already noted, there is xenolithic structure representing incorporated blocks of older material as one extreme and also pegmatites representing final stages of crystallization as the other. These two habits add further to the irregularities and structural variety of formations. The total result is the apparent structural confusion referred to in an earlier chapter. As a matter of fact, these differences are not abnormal to the formations in which they are found if one takes their history into account. They do give, however, the impression of hopeless confusion and a certain vagueness of character which adds much to the difficulty of satisfactory field determination. Not only is the identification of a formation obscured by this variability, but its boundaries are to a large degree uncertain and the identity and interpretation of a given occurrence are frequently difficult or impossible.

Certain structural characteristics may be credited to syntexis or absorption. One of these is a gneissoid structure where the original country rock itself had pronounced structure and especially if it was made up of differing streaks or bands (plate 41).

A result much less uniform than the gneissoid habit is derived from the incorporation of massive material, and this does not develop gneissoid structure without accompanying magmatic movements. The more common effect in such case is a patchy habit of the invading rock not caused by simple differentiation. With magmatic movement it is believed that syntectic portions of the magma may develop striking structural qualities, simulating even the definite banding of an injection gneiss.

The injection type of structure, however, is usually much sharper, and, in the ideal case, has determinable differences of material in the alternating bands. In the typical case, injection may not involve much absorption of the invaded walls or much syntexis, and it ought to be possible to distinguish rather sharply the character of the injection material, connecting it directly with its true source. As a matter of fact, there are all gradations between complete syntexis and clear-cut simple injection, and the commoner occurrences are intermediate in behavior. They have certainly accomplished a good deal of modification of the invaded rock, and have evidently worked over portions of the walls and to some degree invaded the weaknesses of these walls, so that everywhere the invasion matters are intimately intergrown with or mixed with the original rock material. It is perfectly clear in great numbers of outcrops that an injection process has given the fine strikingly banded structures characterizing them. The clearer cases are those in which some transverse cutting of the formation occurs in addition to the banding which usually follows accurately the original structure. This cross-cutting of the structure is always taken as proof of invasion origin, whereas simple banding in the absence of such supplementary evidence has at least other possibilities.

Similar structural habit may possibly be derived by differentiation

Plate 41

Crude gneissoid structure preserved in marginal portions of the Cortlandt series norites near Peekskill. This may be in part an inherited structure from the Manhattan schist, which is the host rock, but is probably chiefly the result of marginal magma movement. Note the faulted band at the hammer. There has been no deformation of this sort since final solidification of the rock.

under movement, as suggested by many writers on such phenomena, but this is not so clear. It is certain, however, that differentiation has some structural possibilities, and this is clearest with the pegmatitic facies. Nowhere in the Highlands does there seem to be such a thing as a segregation mass, such as a marginal ore, but that separations of this kind probably did take place is indicated by the occurrence of magnetite bands of pegmatitic habit which appear to have been injected.

The features referred to in the foregoing paragraphs make up what has been referred to elsewhere as the structural confusion of these older formations. Other features than those mentioned may be encountered but they are all believed to be of the same general genetic meaning.

Forms Represented by the Individual Units

In the series of formations mapped, some are sedimentary beds and have a distribution characteristic of such beds modified by the deformations which are included in their subsequent history.

The Hudson River-Wappinger-Poughquag series, the Manhattan-Inwood-Lowerre series and Grenville formation were primarily sedimentary. Except in the case of the Hudson River-Wappinger-Poughquag series the original structural habit is much obscured by subsequent metamorphic and igneous history. This obscurity is developed to an extreme in the Grenville where a large part of the original bedding is completely destroyed and only the secondary structural habit is preserved. Enough remains, however, to prove that bedding was a fundamental structure in this oldest formation of the region.

The igneous formations occur in a variety of structures, some of which are bosses and perhaps others are laccolithic or sill-like. The behavior of the Canada Hill granite suggests bathylithic relations. Nearly all the igneous masses conform more or less to the trend of the region and the primary control of this trend is undoubtedly the structure of the Grenville. All the larger masses have such relation and form, but a far greater variety of form is represented by smaller units, too small in fact to be mapped. These are the injection bands and stringers as well as dikes and veins which cut through the earlier rock constituting the inclosing walls. The most clearly marked units of this kind are dikes, but their prominence and importance are insignificant compared to the abundance of the pegmatite bunches and stringers, the veins and the injection bands.

It is probably impossible to determine the structural relations of the successive igneous invasions. It is difficult to conceive of the method of approach which might give one of the later magmas opportunity to invade superior rocks in so many places, especially thoroughly crystalline and substantial rocks. That this happened, however, is certain and a magma reservoir of very wide distribution must be assumed. All these necessary assumptions are strengthened by the conclusion reached in the discussion of correlation, which indicates essentially identical igneous formations, and probably actual connection between similar units, occurring in the Adirondacks on the one side and in the Highlands of New Jersey on the other. There is no doubt about the petrographic similarity of these types and the only logical conclusion which seems to be warranted is that certain of these magmatic masses must have had a remarkably widely distributed plutonic development.

The simplest conception would seem to be a great bathylithic mass extending beneath the whole region thus invaded which by its successive manifestations of igneous activity produced the separarate individual units of the series of this area. It may indeed be that the different units are nothing else than successive developments from this single larger plutonic source and that the historical range represented does not transcend the limits of its long magmatic history. In this case, products furnished by the distinguishable field units must represent simply the manifestations of particular periods of magmatic activity. It is difficult otherwise to conceive of conditions which would produce so widely distributed results of similar character with all of this peculiar complexity of structural relation. A plutonic mass capable of producing the first effects, if allowed to crystallize completely, could not, on subsequent igneous invasion, yield the complex structures found so abundantly distributed in this territory. It would seem, therefore, that the fundamental conception, as the source of all the older igneous masses, is that a single great regional bathylith, in its successive periods of activity, has produced all these results as steps in a single but long continued magmatic history.

Deformation Structures

These structures include unconformities, faults, folds and crumples, crush zones, slaty cleavage, shear products, streaked habit and schistosity. Some of these are of large geological significance, such as the unconformities, folds and faults. Some of the other features depending largely on dynamic influence are simply different expressions of metamorphic history.

Unconformities. *Pre-cambrian unconformity.* Only one well-marked unconformity has been demonstrated in this area. This is the unconformity between the gneisses of the Highlands and the Cambro-Ordovician series of sediments. In a few places it is clearly shown that the whole complex structural habit exhibited by the gneisses was developed and exposed to erosion before the Poughquag quartzite was laid down. The form of surface is much modified by subsequent deformation, but the condition found at the best occurrences indicates a comparatively smooth cleanly swept erosion surface so that the first layers of quartzite are in contact with fresh, unweathered gneiss. The quartzite is simple and comparatively pure right from the start and this condition requires not only that erosion should take place under such conditions that the bedrock of that time could be completely denuded, but there must have been unusually perfect assorting and selective concentration to produce such a rock immediately on a granite floor.

The finding of trilobite fragments in certain beds of the Poughquag quartzite shows beyond question that this formation was developed in the sea margin, but it is a striking thing that it has no conglomeratic habit and practically no arkosic composition. It is difficult to see how it would be possible to make such a formation directly from the disintegration of the gneisses. One would expect a history involving the destruction of earlier sandstones of less purity which themselves might have been derived directly from the gneisses. Perhaps there has been such a history, but there is no evidence of it at this point beyond the fact of the purity of the quartzite and the lack of conglomeratic facies. If the Manhattan-Inwood-Lowerre series, however, is, as we now think, older than the Poughquag, it may be that the destruction of members of that series furnished the material of the Poughquag. If that source is not the right one it is difficult to avoid the belief that some other Cambrian or Precambrian formation now entirely missing in this region was destroyed in the making of the Poughquag.

In any case the Cambrian unconformity is a very profound one and undoubtedly marks a great geologic hiatus.

The actual unconformity can best be seen near the north margin of the quadrangle where, in a few places, the quartzite still lies only slightly tilted on the old erosion surface, while the adjacent outcrops of gneiss show their usual steep inclination. No actual observation has yet shown igneous transgression of the Cambrian unconformity in this area although it is possible that this does not hold farther to the south and to the east. It certainly does not hold to the south if the Manhattan-Inwood series is Cambro-Ordovician, but reasons for questioning that correlation are given elsewhere in this paper. One of the latest of the great igneous invasions belonging to the Pre-cambrian series is the Storm King granite which is, we believe, the equivalent of the syenite series of the Adirondacks, and it is most prominently developed in the very section where the unconformity is best preserved. Whatever igneous activity there may be of Post-cambrian age must be much later than this. Even the dikes which cut the Storm King granite do not cut the Cambro-Ordovician series. It is our belief that only the Cortlandt series fulfils this last condition.

It appears, therefore, that the Cambrian unconformity is here a complete break separating both the ancient metamorphics and the whole great series of igneous intrusives from the later Cambro-Ordovician sediments. When one appreciates that these intrusives are large, deep-seated masses of very massive habit and could not possibly have developed near the surface, this unconformity takes on something of its true significance. It represents an erosion interval of vast time during which some thousands of feet of overlying rock must have been removed.

The same unconformity has been found on the west side of Peekskill creek west of Putnam Valley and the relation is the same, except that the erosion surface has been tilted until it stands vertically. But satisfactory exposures are difficult to find. On the east side of the valley, although both the quartzite and underlying granite are well exposed, the structural relation is obscure because the underlying member is a rather featureless granite instead of a true gneiss. It is very significant, however, on this point, since the granite here is the so-called Reservoir granite. It is clear that the granite does not cut or in any way affect the adjacent quartzite. Here also the quartzite member runs so straight and true in spite of the fact that it is tilted into almost vertical position that one is impressed with the evident uniformity and monotony of the erosion surface on which it was formed. The similarity in thickness of the quartzite as developed in this valley and on the northern border seems to argue for the same thing.

A great deal of attention has been given to the question of a possible additional unconformity in this southeastern New York region.

It has been quite natural to look for it at the base of the Manhattan-Inwood-Lowerre series and sometimes an overlap has been postulated to care for some of the descrepancies. Thus far, however, no observations can be said to establish fully another unconformity or even a definite overlap. As a matter of fact very little evidence on that point can be gathered from this particular quadrangle because the Manhattan-Inwood series is too much obscured by drift cover to furnish reliable data.

Pre-Triassic unconformity. Another great unconformity separates the Triassic from all the earlier series, but the structure itself does not figure in this quadrangle since the sediments do not cross its southern margin. It was the erosion work of that interval, however, which stripped some of the Cambro-Ordovician sediments from the region, as may be seen by examination of the basal conglomerates of that age just to the south. It appears, therefore, that the Pre-Triassic erosion interval is a factor of some prominence in a full historical statement although it is not possible in this quadrangle to point out the actual unconformity.

Post-Cretaceous unconformity. The next erosion surface which served at one time as an unconformity was the Cretaceous peneplane which is still to some degree preserved. After it was partly dissected Tertiary deposits must have been laid down on it over this area and still farther inland. These were all stripped from it in preglacial time and the old unconformity (the Cretaceous peneplane) subjected to additional erosion. The result is a somewhat more complex surface forming the preglacial floor than would be possible from a single erosion epoch.

Glacial unconformity. The last unconformity is that between the rock floor of glacial time and the glacial drift itself.

Faults. The region is one of many faults representing several different ages. It is doubtless impossible to determine the age of some of these faults and it is also impossible to locate all of them. The fairest statement that can be made on that point is that they are much more numerous than any inspection of the ground will discover and doubtless many of the most ancient ones are completely obscured by rehealing, injection and complete recrystallization. Thus it happens that most of and perhaps all such structures of Grenville age are lost. It is probable that very few Precambrian faults can be detected with any certainty although evidence of rehealed crush zones may be detected with the microscope.

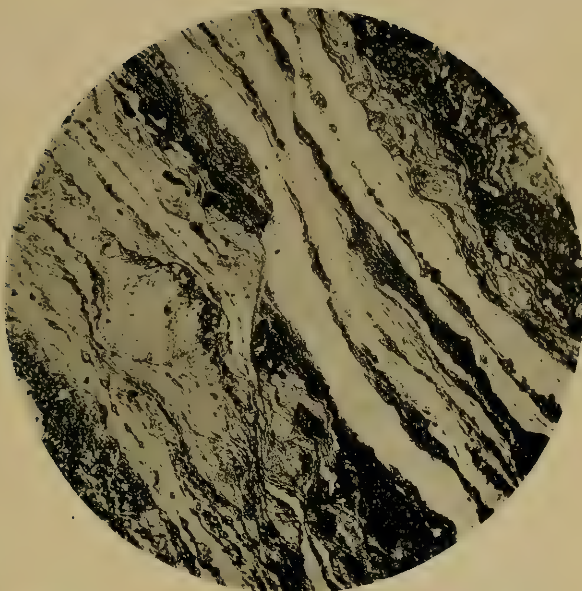
In one of the tunnels of the Catskill aqueduct, however, a typical fault breccia was encountered so perfectly rehealed that the rock is completely crystalline and does not develop weakness on weathering. A second fault of similar behavior developed a very fine shear zone which crosses the northwest corner of Iona island and strikes northeast across the west flank of Anthony's Nose. It is so substantial that the rock within the zone, which is essentially an epidote schist, is as resistant as the adjacent unmodified ground. Other similar shear zones have been noted elsewhere and beautiful shear schists of most remarkable structural habit have been obtained from them (see petrographic section), but there is no topographic expression to emphasize the occurrence of the faults of this type and unless one just happens upon them they are overlooked. They all fall, however, into the lines of general structural trend and undoubtedly they belong to some period of Precambrian deformation. (See plate 42 for illustration of the microscopic features of this material.)

All Cambrian and later faults are probably so imperfectly healed in this region that their occurrence is more readily detected. Although there may be several series, it is doubtful whether more than three can be well established — those belonging to the period of the Taconic folding, those of Appalachian mountain making and those belonging to the Triassic period. Even this much is more than can be differentiated very accurately. The first two are especially confused and perhaps in some cases there has been movement along the same line in more than one period.

It is possible, however, to locate definitely a number of faults which are of large displacement. The Highlands belt itself is an up-thrust block with fault boundaries to the north and south. The fault lines run obliquely to the general trend of the belt itself instead of exactly parallel to it, and it thus happens that cross-faults give an irregular saw-tooth effect to the boundary. Although several have been definitely placed on the map and others are drawn tentatively on the basis of structural weaknesses or radical change in formation, it is certain that many more faults actually occur, and that the district is much more complicated than is shown by the accompanying map.

The faults of largest determinable displacement are the one at the north margin of the Highlands along Breakneck mountain, and the one which extends from Tompkins cove northeastward along the west margin of the fault block of Peekskill valley. In both cases the displacement must be more than 2000 feet to cut out the formations

Plate 42



Photomicrograph of no. 74. Grenville schist. Taken with plain light, magnification about 30 diameters.

Taken particularly to show the minor structural features of a shear zone schist of Grenville age.

Composition chiefly epidote, quartz, feldspar, sericite and titanite. The very streaked structure and augen structure are well developed, but this particular specimen shows in addition, micro-faulting and tendency to rhombohedral fracture.

It is noticeable that the quartz is abundant only in lighter bands and is either introduced or reorganized quartz, in either case essentially introduced at this spot, whereas in some other occurrences of different date the shear-zone material seems to be simply crushed and redistributed materials which belong to the rock without any additions from without. It is possible that this difference in content gives a clue to the age relation. In other words, it is probable that this is a very ancient shear zone of Post-Grenville Pre-cambrian age whose deformation is connected with the healing influences of invading granite. In this case it is probably of Canada Hill age.

actually missing at the fault line. The Breakneck fault is a great thrust, causing the gneisses and granite of Storm King and Breakneck ridge to ride up on the Hudson River slates. The Tompkins Cove-Peekskill Valley fault is connected with a down-dropped block and must have a different structural relation and movement. Since these two are characteristic of the faulting of the region they deserve a special descriptive note.

The Storm King-Breakneck fault. This fault is readily traced by the abrupt change in formations in the northwest corner of the quadrangle, but the ground is badly covered in most of this area and the actual condition is very much obscured. Immediately to the southwest, however, just beyond the margin of the quadrangle on the north side of Storm King mountain the fault is well exposed and very definitely located both on the surface and several hundred feet beneath in the Catskill aqueduct tunnel (Moodna tunnel). The fault plane is simple, and is traceable in fairly definite form for a considerable distance. It dips at not far from 45 degrees to the southeast.

The rock in the hanging wall is the Storm King granite and gneiss, chiefly the mixed types that are called gneisses, rather than the Storm King granite proper. The foot wall is at some places Hudson River slate and at other places Wappinger limestone. In the vicinity of the Catskill aqueduct line, the surface shows slates and the tunnel level 300 feet lower shows limestone. In both cases the adjacent rock is crushed on an immense scale, especially on the foot wall side. For 200 feet the limestone cut by the aqueduct tunnel in the foot wall is crushed and rehealed to such degree that it is absolutely impossible to determine the bedding of the rock. Its exact attitude therefore is entirely unknown. In addition, blocks of slate are dragged into the principal fault zone and some of the gneisses are so crushed and altered as very nearly to resemble the slate.

It is perfectly clear that this is a thrust fault, that the Highlands gneisses and granite have been pushed over the bordering quartzite-limestone-slate series and that the movement has been sufficient to cut out all the quartzite and at most points all the limestone. Probably such patches of limestone as are found are dragged into place by the fault movement. Since the quartzite is rather continuously about 600 feet in thickness in this district and the limestone is more than a thousand feet, it appears that a movement of at least 2000 feet is determinable at this point. The displacement on the average, doubtless amounts to more than this.

The fault zone for the most part is not healed except in the limestone. There is no very satisfactory way of determining the age of this fault because nothing later than Cambro-Ordovician is involved. A considerable development of formations as high as Devonian, however, lies just a little farther to the west, and their position is such as to prove that this faulting was subsequent to their deposition. It therefore can not be earlier than the Appalachian deformation and may be later than that. Considering, however, that the Triassic and later types of faulting are more prominently simple block faulting, this fault, which is a strikingly strong thrust type, must belong to the Appalachian deformation epoch.

No doubt there are many other similar lines in the Highlands that date to the same period. It is possible indeed that some of those on the south side of the Highlands are of this age and may have suffered additional movement in later time. On account of the confusion of the geological formations within the Highlands the amount of displacement is seldom determinable. There is no object in undertaking a detailed description of each fault. They are numerous and of various degrees of prominence.

The Tompkins Cove-Peekskill Valley fault line. The fault which enters the quadrangle from the southeast at Tompkins cove forms, farther south, the division line between the sandstones of the Triassic lowland and the gneisses of the Highlands. It disappears, however, as the principal line a few miles to the south and its place is taken by a parallel fault of like habit lying to the northwest of it. This forms the boundary between the gneisses and the Triassic sediments for many miles in the Ramapo quadrangle of northern New Jersey.

This fault displacement brings phyllites of essentially similar quality to those of Peekskill valley in contact with the granitic gneisses of the Highlands. The same thing is true along the west side of Peekskill valley where phyllites of Hudson River age are brought in direct contact with the granite of Cat Hill and adjacent territory. It appears in this case, again, that 600 feet of quartzite and 1000 feet of limestone are cut out, together with a considerable amount of phyllite, so that doubtless again 2000 feet displacement is not too much to reckon. But in this case the depressed member is on the southeast side and the raised member is on the northwest, just the reverse of that at Storm King-Breakneck, and this result could not be obtained by a thrust movement.

In Peekskill valley the formations are very distinct, and the whole Hudson River-Wappinger-Poughquag series is fully represented. It is clear that a tilted and down-dropped block forms the whole floor of this valley, the formation standing practically vertical on the east side, the principal fault movement being recorded on the west side. Exploratory work has been carried on in connection with the Catskill aqueduct investigation which gives accurate data on the location and attitude of the rocks across the whole valley, even where they are heavily covered with drift. The major structure, therefore, is very well known and the main facts on those explorations may be found in N. Y. State Mus. Bul. 146.

The striking thing in this isolated block of Cambro-Ordovician sediments is the close isoclinal folding which seems to have tripled the thickness of the limestones, while the block shows down-faulting of a sort that is difficult to associate with the type of folding represented. It seems necessary, therefore, to invoke the aid of deformation of two periods, first a close folding of the Appalachian type which probably took place in Appalachian time. Second, a down-faulting and tilting of the block which belongs to the period of Triassic deformation. The chief deformation zones of these two periods are nearly parallel and this causes confusion as to which period really caused the folding. Also it is possible that some folding and shearing accompanied the block faulting. It does not seem reasonable, however, considering the simplicity of the typical Triassic blocks to charge much of the folding of this isolated block to the deformation of Triassic time.

It is entirely possible that block faulting preceded the Triassic period of deposition also and thus outlined some of the principal areas of that formation. The great Triassic block which carries many thousands of feet of sediments on the west side of the Hudson in northern New Jersey and adjacent portions of New York, would be such a case. At the extreme northeast point of this acute-angled block the unique igneous intrusive masses known as the Cortlandt series are located. This intrusion seems to have followed the weakness developed at this angle where several faults converge.

It is not possible to say how many dislocations belong to the Triassic deformation. Undoubtedly there are some examples in the Highlands and also north of the Highlands, but nothing of equal prominence to this Peekskill Hollow fault presents data of decisive enough character to warrant description.

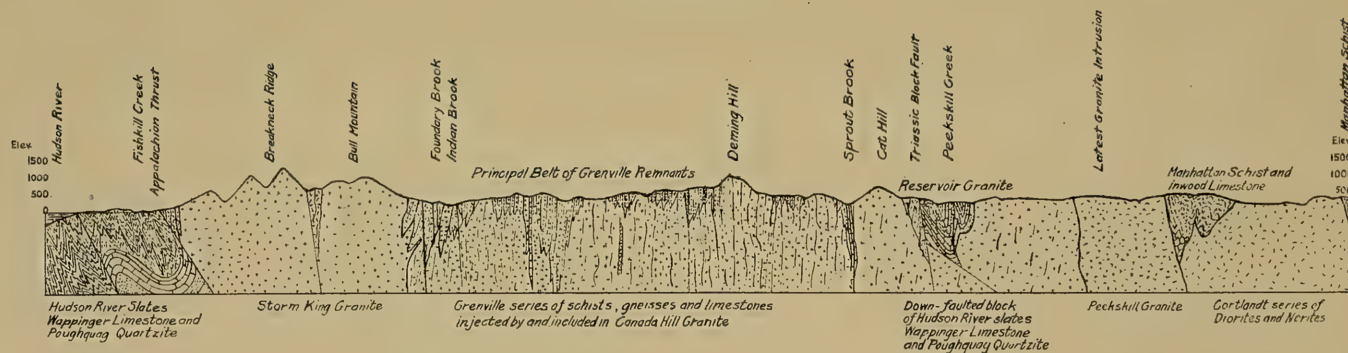
Possible other types. The sudden ending of the series of crystalline schists and limestones represented by the Manhattan-Inwood formations, and their attitude at the boundary with the gneiss in the southeast quarter of this quadrangle suggest a sharp flexure along the margin which may have the same meaning as a fault line. It is a question whether that boundary might not better be represented as a fault. It is not clear, even so, whether it would represent any different age relation from those already discussed. The reason for calling attention to it is the suspicion that this particular deformation may date to a much older period than either of the two just described, and this may account for the sudden disappearance of the Manhattan-Inwood series farther north. It is, in other words, connected with the very confusing problem of the interpretation of the Manhattan-Inwood series.

Minor structures. In addition to the faults of a major sort, there is an endless variety of crumples, minor faults, drag effects, etc. which are the incidental accompaniment of major deformation. In some cases they are undoubtedly simply secondary and tertiary and minor drag effects. In other cases a similar appearance is created by movements in the magmatic masses, where partially digested slabs of older rocks are distorted or where poorly distributed matters are drawn out and twisted by magmatic movements. These give great variety of appearance to the formations under discussion, but they do not deserve detailed treatment here.

Folds. One's first experience with the Highlands gneiss structural features, especially the high angle of dip which nearly all formations of the district have, leads one to assume a very profound folding as one of the contributary causes. Undoubtedly much folding has taken place and such structural features as belong to folds are especially well developed in the Cambro-Ordovician and in the Manhattan-Inwood series. But it does not appear, after further consideration, that much of the structural detail of the gneisses or of the banded and streaked rocks of mixed origin have been greatly influenced by folding, except such as may date back to Grenville time.

It is clear, from knowledge of the structural history of the general region to which this area belongs, that it must have been within reach of the deforming forces of every mountain-making period since Grenville time; but it may very well be that deformation in the form of folding has not affected these massive members of the Highlands belt as much as the more superficial and less competent overlying sediments. It must be appreciated that the Highlands belt

Plate 43



Geologic cross section of the West Point quadrangle along the line A-A on the geologic map. Drawn in a general n. w.-s. e. direction crossing the entire Highlands belt of granites and gneisses from the slates of the north side to the schists of the south.

has been thrust up to a much higher relative position with respect to the bordering country, both north and south, in comparatively recent geologic time. Part of the uplift certainly dates from the Triassic, since which time there has been no folding in the region.

It is the writers' belief that the Grenville structural habit and attitude and distribution indicates folding of that formation dating back to very ancient Precambrian time. There is no claim that distinct repetition of beds can be detected, but the very definite northeast-southwest trend and the marked control over all igneous intrusions resulting in a similar orientation of them indicate that this formation, which is the oldest of the region, must have had this structure before the igneous history began. The only way by which a series of sedimentary strata can exhibit a regional trend is by deformation and we regard this regional habit therefore as satisfactory proof of the folding of the ancient Grenville.

If the Manhattan-Inwood-Lowerre is also Grenville, as we are now inclined to believe, much of its folding must also be Precambrian.

The Post-Ordovician or Taconic folding must have affected the region also and later the Permian or Appalachian folding was imposed upon it.

Thus it happens that the Cambro-Ordovician sediments to the north and the down-faulted block in Peekskill valley, and the schists and limestones of the southeast quarter are all much deformed by folding, but to which of these periods the chief deformation should be credited is a matter of much obscurity. It may even happen in the case of the down-faulted block in Peekskill valley that its folding is in part connected with the Triassic faulting. On the whole, the chief folding belonging to the members on the south margin of the quadrangle is of comparatively ancient time, and that affecting the Cambro-Ordovician of the north margin belongs chiefly to the period of Appalachian folding. All the folds trend northeast-southwest except for minor flexures and local pitches and the deformation of every period seems to have had nearly the same orientation. Most of the folds are asymmetric and sometimes overturned toward the northwest, and the major structures are accompanied by all the normal minor folds and crumples of the second, third and fourth and still higher orders which might be expected in a region of such extensive deformation.

ECONOMIC AND ENGINEERING GEOLOGY

Mineral resources

A region of such variety of rock type would lead one to expect that the mineral and structural material resources of the district might be very promising indeed. This is all the more expectable when one takes into account the complicated igneous and metamorphic history which might readily have produced important mineralizing effects. It is somewhat surprising, therefore, to find that mineral resource development has been very limited. At numerous places quarries have been opened and rock for structural purposes has been produced. At a few places economic minerals, such as pyrite and iron ore, have been worked in former times. Sands and gravels have been produced as well as road metal, lime and clay. More recently, investigations have emphasized the presence of material for crushed rock, high-grade silica, water and other things. These will be taken up briefly.

Building stone. Large amounts of stone suitable for structural use are available. The chief items are granite, quartzite, limestone, marble, and gneiss.

Granite. A very excellent and unusually attractive granite has been quarried 2 or 3 miles east of Peekskill at two places, both in the younger granite formation, known in this paper as the Peekskill-Mohegan granite. A very light-colored, almost white granite was quarried in a portion of the area nearest to Peekskill usually known as the Peekskill granite quarry. This quarry furnished stone for the New Croton dam, and although it is very suitable for building purposes and because of its fine color, would be a strong competitor in the New York City market, the quarry is not now worked. This is in large part because of troublesome jointing conditions. There is nothing against the quality of the stone and it is possible that at some other point work could be established where excessive jointing would not interfere.

It is an interesting bit of history with regard to this quarry that suit was brought against the operators, who worked it for the supplies used in Croton dam, for ruining the quarry, the claim being made that the jointing condition now seen in it was largely produced by extravagant and careless use of explosives in quarrying. Although it is true that the use to which the material was to be put, made it possible to utilize much rough broken rock and that on this account very careful handling was not so necessary as for regular structural stock, yet it is perfectly clear that the jointing which has caused the real trouble is natural.

A mile further east across a stretch of low-covered ground, the Mohegan quarries lie in the same formation. Several openings have been worked at this point, most of them comparatively small. A peculiar color quality is produced here which makes the stone unusually attractive to architects. The Mohegan granite has been used in the Cathedral of St John the Divine of New York City. The principal color is a sort of buff, which is very unusual for a granite, but it seems to be strictly a primary color.

Both of these quarries are marginal in the granite mass which is genetically related to the Cortlandt series. No other places have been worked in this rock.

A granite quarry was opened some years ago on the south side of Breakneck mountain and a considerable volume of stone was removed. It was abandoned, however, apparently because of the close jointing and the structural irregularity of the stone. This rock is the Storm King granite type which has a rough gneissoid habit and strong pegmatitic tendency. Both of these tend to make the quarrying of massive blocks difficult. These characteristics do not necessarily interfere with use for rougher purposes than building stone, such as crushed stone or cyclopean masonry or for foundations; but it is doubtless the difficulty of working, especially the tendency to produce irregular and curved surfaces in quarrying, rather than its petrographic quality that has discouraged working.

At many other places small workings may be seen, but most of them have figured only in local use and are so placed that the transportation handicap could not be overcome for a wider market. High-grade granites from other sources meet the requirements of the market so fully that it would require extraordinary conditions or particular quality to gain a position of economic importance.

It is true, however, that granitic rocks both of massive and especially of gneissoid varieties occur in very great abundance in this quadrangle and could be produced in large quantity. Their quality is good enough to meet all normal requirements, but considering all controlling factors it is not likely that large supplies will be drawn from any of this ground for building stone purposes.

An occasional gneissoid type of rock is found to give rather good architectural effect and it may possibly be that such quality of rock will be in higher favor in the future. If such a thing should happen it would be difficult to find a more promising field of development than the gneissoid granites of the Highlands of New York.

Limestone and marble. A very high-grade, finely crystalline limestone occurs at Tompkins cove, following the margin of the down-faulted block at that point, and extends from the river southwestward to the limit of the quadrangle. The beds stand at a high angle and are associated with a phyllite in similar manner to the association of these two rocks along Peekskill creek. They are judged, therefore, to belong to the Hudson River-Wappinger series and the Tompkins Cove limestone is accordingly correlated with the Wappinger. Beds vary greatly in quality, some of them being highly siliceous and certain beds more strongly magnesian than others.

The density of the stone, however, and its large development, together with its excellent location for cheap transportation as well as other favorable conditions at this locality have made the working of this stone a very large and prosperous undertaking. The stone is as good quality as can be produced from limestone. It is used very extensively for ordinary crushed stone purposes and the market in New York and vicinity, where it supplements the trap rock and other crushed stone demands for various structural purposes, absorbs the total production.

The rock is rather strongly metamorphosed and has developed silicates to some degree from its original impurities, but this transformation has not made it coarse and granular and weak to the degree attained by some of the other limestones, notably the Inwood.

The following analyses represent the chemical quality of the stone:

1 Analysis recorded in New York State Museum, 51st Annual Report, 2:450 (1897); also in Bul. 44, p. 438 (1911):

SiO_2	12.00
Al_2O_3	4.13
Fe_2O_3	1.05
$CaCO_3$	23.34
$MgCO_2$	16.74
CO_2	39.1

2 Analysis made by Richard K. Meade, Baltimore, Md. (1919); furnished by Calvin Tompkins of the Tompkins Cove Stone Co.:

Silica	8.10
Iron oxide and Alumina	1.24
Carb. of Lime	54.50
Carb. Magnesia	36.36

3 Analysis made by Edison Company (1908); furnished by Calvin Tompkins of the Tompkins Cove Stone Co.:

Carb. of Lime	54.00
Carb. of Magnesia	36.00
Silica	6.00
Oxide Iron and Alumina	4.00

4 Analysis made by A. A. Brennan, 97 Water st., New York (1919); furnished by Calvin Tompkins of the Tompkins Cove Stone Co.:

Two samples of limestone were determined for magnesium carbonate content

No. 6223 (blue)	27.67% Magnesium carbonate
No. 6224 (grayish white)	30.71% Magnesium carbonate

A continuation of this same formation may be traced along Peekskill hollow for several miles, but it is everywhere covered rather heavily with drift and does not stand favorably for exploitation. This condition is somewhat better as one traces the beds to the northeast, but transportation becomes more difficult and the prospect of competing successfully with the other limestone quarries situated on the Hudson river is questionable.

On the opposite side of the river from Tompkins cove, at Verplanck point, there are other quarries also in limestone, which have been extensively worked. They are quite as favorably located as those at Tompkins cove, but have not been developed so systematically and the character of the stone is somewhat different, in that metamorphism in the direction of strong, rather coarse recrystallization is much more pronounced. This affects the quality of the stone to some degree, and it is therefore placed at a disadvantage since the fine-grained varieties are preferred. There is a large available supply here, however, and certain beds are undoubtedly serviceable.

Crystalline limestone of Inwood type occurs in the southeast corner of the quadrangle between Yorktown Heights and Amawalk. The rock is a true marble in its crystalline habit and certain beds are quite as good as the Tuckahoe marble. The rock is, however, rather coarse and soon shows the effect of the weather. On this account the Inwood type of stone has little market. Although it would be possible to produce any quantity of this stone from this and adjacent areas farther to the south it is not likely that large development will be undertaken chiefly because of the short life of the stone.

A quarry was at one time worked in the Sprout Brook limestone, which is an interbedded Grenville limestone. It is an exceedingly complexly metamorphosed rock with much deformation and igneous injection and development of silicates. The structure is very variable, the quality is quite erratic and the grain is prevailingly coarse. On account of these facts, the rock is not so serviceable as the others for the ordinary higher grade purposes. It was, in former years, burned for lime and was used also in connection with local iron smelting; but it has not been worked now for many years. A very large development of this limestone is found in Sprout Brook valley, however, and any special quality belonging to this type could be produced on a large scale.

Lime. In earlier days lime was produced from certain of the limestones in this area. At present no lime burning is practised although certain beds of the Inwood are used in this way at Ossining, a few miles farther south. Undoubtedly similar quality of product can readily be made from the limestone of this quadrangle, but a high-grade quality to meet the competition in the market is not likely from any of these formations.

Quartzite. A belt of quartzite approximately 600 feet thick extends along the east margin of Peekskill hollow for many miles. This is the Poughquag quartzite belonging to a down-faulted block. It stands almost exactly on edge and its southern exposure is in a hill at least 100 feet high, not far from the Hudson river. It is almost an ideal location for working, but nothing has been done beyond investigating the quality. It is a high-grade quartzite rock carrying only a very small percentage of impurities and has been examined on this account for its possibilities as a glass sand. These results have been reported by R. J. Colony in a recent bulletin of the New York State Museum[18] in which the following analysis of a mixed sample is recorded:

SiO_2	95.51%
Fe_2O_3	0.27%
Al_2O_3	2.35%
CaO	0.07%
TiO_2	0.39%

Mr Colony notes that not all the silica in this rock is quartz, however, that feldspar grains are numerous and no doubt these grains are the chief source of the alumina.

Similar or even better quality is to be found on the north margin of the quadrangle where the Poughquag is exposed. None of these occurrences, however, is so well situated as that at Peekskill creek for cheap transportation and unless a very high-grade quality

[18] N. Y. State Mus. Bul. 203–4, p. 22 (1919); also p. 8–9.

could be discovered in those beds it is not likely that any of them would be worked for the present.

A very small outcrop of quartzite has been noted east of Peekskill along the east margin of the Peekskill granite area, but its extent is undetermined and its quality is unknown.

If a high-grade quartzite could be shown to have a quality for structural purposes not fully met by the siliceous limestone and trap and other rocks, which supply stone in such immense quantities and under such favorable conditions along the Hudson river, it might be that the quartzites of this quadrangle would ultimately become the foundation of a large industry. The question has received attention recently, but thus far no development has been undertaken.

Iron. A good many years ago iron was produced from this quadrangle at several points and a furnace was located at the mouth of Peekskill creek. A narrow gauge railway connected this plant with the producing properties, but this, together with the plant and the workings, have been abandoned for so many years that only obscure ruins remain. Iron was brought from the belt of iron-bearing rocks which follows the west side of Sprout Brook valley and extends almost exactly through the center of the quadrangle in a long belt running northeast-southwest. The ore is magnetite and has pegmatitic associations and probably igneous origin. The bodies proved to be rather small and the mineral considerably mixed with silicates. Doubtless large quantities still remain and it is possible that modern treatment of some of these deposits would be found practicable. Occasional occurrences of similar sort lie outside of this belt already referred to, but nothing of consequence has been noted of any different relation or origin.

Pyrite. At a point somewhat east of the summit of the mountainous mass known as Anthony's Nose, was formerly located a mine producing sulphide of iron, the product of which was used in an acid plant near the present Highlands station on the New York Central Railroad. This plant was in operation up to about 15 years ago, but has been abandoned in recent years. Its total supply was not obtained from this mine, however, and finally the mine was not depended upon at all.

What the actual condition is at the old mine can not be determined because of danger of entering the workings. It is clear, however, from inspection of the occurrences at the surface and from the material on the dump that the ore was associated with pegmatite much like that of the magnetite deposits. In fact magnetite also occurs in this deposit. Remarkably large crystals of the constituent minerals are developed here, including immense slabs of hornblende and masses of pyroxene. This agrees well with the assumption of igneous origin connected with pegmatitic development. No other deposit of similar nature seems to have been worked at any time.

Pyrite, however, is not at all rare in the Grenville and to a small extent in some of the other formations, but none is known with high enough content to be considered workable. The quality of material at the Anthony's Nose property was said to be poor because of the presence of pyrrhotite in addition to many intermixed silicates.

Sand. The glacial deposits, a large amount of which is modified drift, contain numerous occurrences of washed material and fairly well-sorted material answering the purposes of stuctural sand. No very high-grade deposit, however, has been examined, but certain occurrences situated in proximity to engineering undertakings, where such material was needed, have been extensively used. One of these is known as the Horton sand deposit at the north end of the Garrison tunnel a short distance east of Garrison. The deposit occurs in a typical kame formation, is very variable in quality and of comparatively limited usefulness although it has considerable local extent and was extensively used in the building of the Catskill aqueduct.

Other similar occurrences may be found and some are used for small local supplies, but there is nothing of extraordinary value except perhaps a gravel deposit on Jones point which has now been completely worked out.

Gravel. At Jones point, on the Hudson, just opposite Peekskill, a rather remarkable deposit of coarse gravel has been worked for many years but is now practically exhausted. It is washed glacial material of the heavier sort from which practically all the clay and finer material have been removed. The pebbles were largely hard crystalline types and on this account produced a very high-grade gravel for road metal use. This at one time was in great demand. Search has been made for similar deposits elsewhere to supplement the declining production from this place. Although gravel deposits are not rare, a high-grade pebble content is surprisingly rare and thus far none has been found to meet the requirements so well as that at Jones point. Most deposits have too much sandstone, shale and limestone and too little crystalline rock content.

Road metal. Crushed stone for structural purposes, including

Plate 44

Modified drift in the Kame deposits east of Garrison on the Horton ground where it is cut by the Catskill aqueduct.

This is at the north end of Garrison tunnel at an elevation of about 400 feet.

road metal, is produced at Tompkins cove in very large amount. It has also been produced at Verplanck point and in former times some production was furnished from the Iona Island gneiss and from the Storm King granite at Storm King mountain. None of these is now active except the Tompkins cove plant.

Possibilities of producing any quantity of granite gneisses and similar rock are very good indeed, but it does not appear that the quality of material produced for this purpose from such sources can compete with the stone already in the market from the trap formations and the siliceous limestones. It is possible that some of the quartzites may furnish a particular quality, but these have not been tried out and as far as known, they do not promise a quality superior to the trap in any case. As long, therefore, as trap supplies are obtained at a moderate price, it is not likely that any of these possible sources will be used extensively. They undoubtedly will be used locally for many purposes and especially for road building. This quadrangle, in short, contains its own structural material for all sorts of building and construction purposes but does not promise any considerable supply to the stone market.

Clay. Clays are developed along the Hudson river in considerable quantity, but the workable deposits are chiefly beyond the limits of this quadrangle. The large Haverstraw brick plants lie just south of this quadrangle and others of similar sort occur to the north. One at Dutchess Junction in the northwest corner of the quadrangle is worked on a large scale. Smaller amounts occur on Verplanck point on the south. The origin of these is the same as the well-known Hudson River clays connected with the close of the glacial period. The quality is suitable for common brick manufacture. No large industry could be established, however, within the limits of the quadrangle except such development as the deposits near Dutchess Junction will afford.

Water. The region has a rainfall of 48 inches and the streams from the mountainous and sparsely settled portion of the region furnish excellent water for all ordinary uses. Some of these are used locally as water supply for such places as Peekskill. Local supplies for farms or individual use are not difficult to secure in most districts by wells.

No water of extraordinary quality is known within this region. An occurrence of rather surprising behavior, however, has been encountered on Foundry brook not far from Nelsonville above Cold Spring. Here a boring put down through the drift and into rock, for exploratory purposes in connection with the Catskill aqueduct investigations, encountered a water-bearing zone in the crushed gneisses or granites along a fault, and a flowing well was thus developed. This furnished the basis for an extra damage claim in connection with the condemnation proceedings and the nature of that claim is described in connection with engineering problems on a later page. The quality of the water is good but nothing extraordinary for such a region. Doubtless similar quality can be obtained elsewhere at numerous places, but it would not be easy to discover another combination of circumstances which would be certain to produce a flowing well.

Emery. The Cortlandt area near Peekskill is one of the very few places in America from which emery is produced. These deposits occur in the norites of the Cortlandt series as rather limited local developments. They exhibit very unusual mineral association, among which are magnetite, corundum, spinel and epidote in addition to or instead of the usual minerals of the norite series. These patches usually have a distinctly banded structure which is normally lacking in the norites themselves and which suggests the existence of some older rock which has been in large part destroyed, but whose structure is in part preserved. They probably represent xenolithic masses which have been able to attract from the magmas in which they were immersed or have at least helped to fix certain constituents which together with those already in the rock have given the abnormal minerals of the emery deposits.

This origin was suggested by the senior author some years ago during his study of the Tarrytown quadrangle and the detail has been worked out in a petrographic study by G. S. Rogers,[19] whose dissertation on the Cortlandt series furnishes the best description of this area. The following items bearing on the emery deposits themselves have been extracted from his paper. Description of the formation is given in a different section.

" The abrasive, emery, is an intergrowth of magnetite and corundum. It occurs in veins and pockets with occasional well-developed lenses. The types are spinel emery, pure emery, feldspathic and quartz emery schist, associated with norite and sillimanite schist."

Rogers summarizes his description as follows:

" 1 The ore usually occurs in a region in which mica schist inclusions are abundant and often within a hundred feet or so of such an inclusion, and the largest (McCoy, Dalton etc.) are within 1000 feet of the border of the Cortlandt series.

[19] Rogers, G. S., N. Y. Acad. Sci., Annals, 21:11-86 (1911).

2 The ore is always in sharply defined veins, pockets or lenses, but its constituents often occur disseminated through the rocks immediately adjacent.

3 The ore is immediately associated with abnormal rocks, containing sillimanite, cordierite, garnet, quartz, or allanite, which are found nowhere else in the area, except around certain schist inclusions near Crugers; or more rarely it adjoins rocks which are normal except for the spinel scattered through them. There is often a great abundance of biotite around the ore, which is also characteristic of these inclusions.

4 These rocks often exhibit evidences of shearing, faulting or cracking, which is rare in other parts of the district, except around schist inclusions."

The theory advanced to account for the occurrence is that the emery is formed by the absorption of the Manhattan schist in the basic magma of the Cortlandt series. The streakedness of the ore resembling the structure of a schist, and its occurrence near the contacts of the igneous rock and around schist inclusions, the presence of sillimanite, garnet and biotite, and the gradation from norite, through emery into schist, are the chief arguments for the theory advanced.

Considerable amounts of material of this type are available from the district. It is not a high-grade product, however, and considering the fact that the market is chiefly supplied by other types of abrasives and that a higher grade emery comes to the market from foreign sources there is no immediate prospect of more extensive development, although it is likely that small production will continue for an indefinite time. This is an interesting economic resource, although it is not one of large consequence. Its interest centers largely in the rarity of its mineralogy and in its origin.

Ball mill pebbles. An interesting special use of the very hard and tough material forming the emery deposits has been tried out by Edres Herbert. He conceived the notion of using this material in ball mills for grinding purposes as substitute for flint pebbles. The foreign supply of flint was cut off by the war and substitutes were in demand. Preliminary tests have shown unusually encouraging results and there seems to be promise of a limited use of this kind for this material. Its weight and toughness are two points in its favor.

Graphite. The mineral graphite is not at all unusual in the Grenville rocks. It is found in considerable abundance in certain of these formations along the eastern side of the Hudson from Garrison southward, but no occurrence is known which would encourage exploitation.

Most of these occurrences are undoubtedly of the same general origin as is usual in the complete metamorphism of sediments, and this particular content probably is derived from original carbonaceous materials which belonged to the rock. Flakes of graphite occur in the schists and gneisses and limestone members, but it is more apparent in the very schistose rocks than in the others. An occurrence of this same type at Tuxedo, 20 miles farther west, was investigated with considerable care a few years ago by Mr Lorillard of Tuxedo, and there have been other attempts to determine the workability of this material; but thus far none has succeeded, and most investigators have gone no further than the preliminary stage. The prospects in this quadrangle are certainly no better than at many other points and there is no likelihood of them proving valuable for this mineral.

A very interesting occurrence of the same mineral in entirely different form is found near the west margin of the quadrangle west of Dunderberg. This is an occurrence of graphite in a pegmatite vein. The graphite occurs in large plates and is associated with mica and quartz and feldspar. It is not developed on a large enough scale for exploitation, but it represents a not uncommon type of occurrence. The graphite must in this case have an igneous history. Similar occurrences are found on the east side of the river northwest of Garrison.

General summary of economic resources. On the whole, the economic resources of the quadrangle are not extraordinary in any respect. For a region of such complexity of geological structure and history they are rather strikingly insignificant. There are practically no mines and the prospects of furnishing products of very high grade of any sort are, to say the least, only moderate. The only industries of this sort which may lay claim to rather unusual quality in the market are those connected with the Tompkins Cove limestone, the Peekskill granite, and the Peekskill emery.

Engineering Undertakings

The Highlands of the Hudson lie directly across one of the greatest lines of transportation of the United States. Such transportation facilities as the Hudson river itself presents, raises no question at this point because the river is deep and wide enough to accommo-

The Storm King crossing of the Catskill aqueduct.

The building in the foreground is the gate chamber over the Breakneck or uptake shaft of the 1100 foot pressure tunnel under the Hudson river at the narrows forming the north gateway to the Highlands.

The southerly face of Storm King mountain, doubtless steepened by ice plucking, may be seen across the river. The gorge itself was overdeepened by the crowding of the ice through this gateway, and the deepest known spot in the course of the Hudson is in the middle of the river at this point.

date almost any type of vessel. In railroad building, however, the conditions are not so simple. The sides of the gorge at many places reach the water's edge in comparatively steep cliffs or rugged mountain sides and the upland is too rugged to encourage the location of any such transportation line. Two railways, however, follow the Hudson river. The difficulties encountered by them are in part met by tunnelling and in part by filling and stabilizing the natural fill of the river gorge itself. No extraordinary problems have arisen in this connection.

A recent piece of engineering work, however, the Catskill aqueduct, has introduced several less common problems of sufficient complexity to warrant special note.

Those of chief geologic interest are: (1) the Hudson river crossing at Storm King, (2) Bull Hill tunnel, (3) the Foundary brook crossing, (4) Garrison tunnel, (5) the Sprout brook section, (6) the Peekskill Hollow section.

In a region of such complex structural habit and variety of relief, considerable difference in the practical problem is presented at these different localities. Thus it happens that in certain cases it is a matter of depth of preglacial channel; in others, a matter of quality of rock or depth of decay or source of structural material or water behavior. The cases selected for illustration are typical of problems belonging to engineering geology in a region of this kind.

The Hudson river crossing from Storm King to Breakneck mountain. The Catskill aqueduct approaches the Hudson from the west at hydraulic grade, across the country back of Newburgh which is something over 400 feet above sea level. It is necessary either to keep this level by some sort of structure or maintain the pressure in some sort of conduit or pressure tunnel across the Hudson river to the east side, so that a 400-foot level may be maintained again across the Highlands. The engineers in charge of this work decided in favor of a pressure tunnel in bedrock as the most permanent and practical design for this undertaking, and the location chosen for the crossing was between Storm King and Breakneck mountain in the northeast corner of this quadrangle.

A careful study of other possible crossings was made by the senior author of this bulletin before this selection was made and it was finally determined on several accounts that this location had more known points in its favor and was more defensible geologically than any other. All the more favorable locations were in the Highlands within the bounds of this quadrangle, but several others outside of this area were also explored in some detail.

The strongest point in favor of the Storm King crossing was the evidence that the tunnel beneath the Hudson would lie in a single type of rock, the Storm King granite, whose structure is more massive and uniform than any of the others.

There seemed to be less danger also from faulting in that particular spot than most other places along the Hudson river. The fault question indeed was one of the most vital in the problem. All but one other of the locations studied involved certainty of weakness within the Hudson river gorge itself. The quality of rock and the faulting problem were, therefore, the most decisive factors.

A second-choice location was between Crows Nest and Stony Point and as conditions are now known there is no particular reason to disfavor such a crossing, as far as geological behavior is concerned. A third possible crossing, near West Point, involved a great crush and fault zone, which the river follows from West Point to Fort Montgomery.

All the proposed crossings north of the Highlands involved tunnels in the Hudson River-Wappinger-Poughquag series with a certainty of many faults and other structural difficulties and a very long stretch under pressure. No place superior to the Storm King location was available therefore on the most important counts. It was formerly assumed by many geologists and engineers that the Hudson river followed a fault line and that the gorge probably could not be crossed without encountering the troubles of the accompanying fault zone. Studies made at the time this problem was undertaken, however, indicated that most of the lines of the great fault system run diagonally northeast-southwest, crossing the river rather than following it, and that this is strictly true in the section between Storm King and West Point. Later explorations and observations made during the actual construction of the tunnel have fully sustained this conclusion so far as the Storm King-Breakneck locality is concerned. With regard to the other places, of course, no additional information is available.

After choice of location, however, the chief controlling question was the depth of the preglacial channel. Before construction could begin and even before final estimates could be made, a particular depth for construction had to be determined upon, a matter of no easy solution.

It was supposed by many engineers that the bottom of the Hudson had been determined at New York City as approximately 300 feet below sea level; but when this question was studied fully, it became

Plate 46

Break Neck mountain, taken from the river, showing the massive habit and strongly and irregularly jointed structure of the Storm King granite which crosses the river at this point.

apparent that the actual bottom of the Hudson at its deepest point was not determined at all. It was also apparent that with the very deep gorge extending out to sea for 75 miles, measuring approximately 4000 feet deep on the submerged margin of the continental shelf, a good opportunity was presented for a much deeper Hudson gorge in the district under study. It was soon found also that at no place along the Hudson between Albany and the sea was the depth fully determined. Explorations therefore had to be undertaken. These involved exploratory borings in the river and, ultimately, inclined borings from shafts located on either side of the river.

From outside sources of information and especially from wash borings put down in the vicinity of New Hamburg it was estimated that the depth to the rock bottom of the river would be more than 200 feet, but relying on the belief that the 300-foot depth reported at New York was reasonably correct, it was argued that the river gorge should not be any deeper than this and probably not so deep at the Storm King crossing. It was somewhat of a surprise, therefore, when one of the early borings in the river considerably to one side of the center, penetrated a great variety of materials, chiefly bouldery and gravelly drift, to a depth of 500 feet before striking rock. Great difficulty was encountered in putting down these test borings. Seldom has an exploratory investigation been undertaken under more discouraging conditions. Because of the tidal flow and river current, the machines had to be perched on platforms or fastened to the casings that were established as the first part of the boring operation, while the power and other equipment was located on scows anchored beside them.

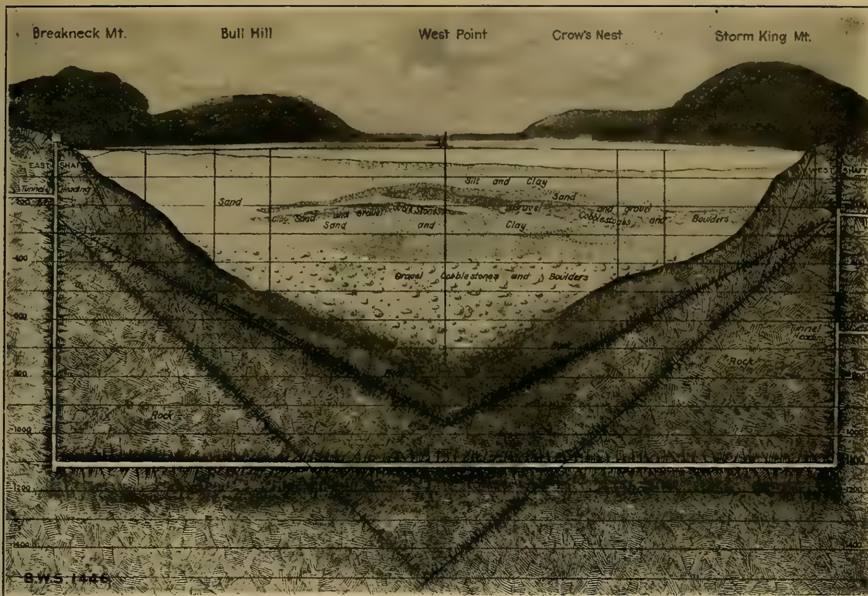
The most difficult of all ground to penetrate is just such mixed structural materials as was found at this place. It is necessary in such case to start with a very large diameter casing, driving it as far as conditions will allow, and then, when halted by material which can not be further penetrated, introduce some form of churn drill or similar device which can be worked inside of the first casing tube. This permits additional progress through boulders or other obstructions, but at the same time reduces the size of the bore. As soon, therefore, as material is encountered which slumps, it is necessary to put down another protecting casing inside the first and proceed with it in the same manner as far as it will go. This is a time-consuming and very expensive process and where very deep borings have to be made under such conditions, many additional difficulties serve to complicate the problem. For example, the Hudson is a great traffic-way. Great lines of canal boats pass in tow up and down the river. With current and tide these are difficult to manage, especially in attempted avoidance of these boring rigs placed adjacent to the main channel. As a result some of these boring rigs were wrecked after long time and much money had been spent on them.

The margins of the river, however, came ultimately to be very fully explored, and the general form of the gorge was outlined to a depth of about 500 feet on each side. The central portion of the channel, however, for a width of something like 1500 feet was still unexplored, except by one boring which ultimately penetrated to a depth of 765 feet without reaching bedrock.

Such results aroused much suspicion in the minds of the engineers responsible for this work and so much time had been consumed that uncertainties of this section were considered to be the most questionable feature of the whole aqueduct line between New York City and the Catskill mountains, endangering, in the minds of some, the success of the whole project. It was felt, therefore, that complete information must be obtained in some other way.

Enough confidence was placed in the geological conclusions and evidence, however, to warrant continuation of the plans adopted and the construction already started at other points, to encourage expenditure on permanent work at this crossing. The plan adopted finally was to sink full-size working shafts on each side of the river so that they could ultimately be used for the finished tunnel. After sinking these to a depth of about 200 feet, rooms were cut in the solid rock and diamond drills were set up in them, one on each side of the river, at suitable angles to penetrate the ground underneath the middle of the river. The first trial was made at an angle which when projected reached a depth of 1400 feet at their intersection under the middle of the river. The geological results were satisfactory. Subsequently the drills were set up again at a flatter angle to intersect under the middle of the river at a depth of 950 feet. This also gave eminently satisfactory results, indicating the Storm King type of granite for the whole distance in both sets of borings. Surveys of the drill holes for deflection or deviation from the true angle indicated comparatively little correction and these two sets of borings were thereupon considered complete substantiation of the geologic conditions expected, as previously interpreted, and sufficient proof of the actual conditions to be encountered to warrant the immediate letting of contracts and the beginning of construction of the Hudson River pressure tunnel.

Plate 47(a)



Diagrammatic cross section of the Hudson river at the Storm King crossing, looking south, showing the completed aqueduct tunnel, the exploratory borings made in the river and the inclined diamond drill holes made from the two working shafts

Plate 47(b)

A diamond drill set up in a room cut out of granite work in the shaft at Storm King Crossing, at a depth of over 200 feet, drilling the inclined holes to explore the ground beneath the river

It is still uncertain, however, just what depth the preglacial gorge has. The boring from the river surface had reached only 765 feet and the borings from the side shafts had tested solid rock at 950 feet. The old channel bottom therefore lies somewhere between, but at just what point there is no possibility of knowing.

Assuming, therefore, that there might not be much of a thickness of rock above the 950 foot point reached by the shallower oblique borings, the engineers in charge of the project decided to locate the tunnel at a depth of 1100 feet so that there would be more than 250 feet of solid rock above the roof of the tunnel. This is the way it was constructed.

Two dangers were faced in constructing a tunnel of this kind, first, that crevices or broken ground would be encountered, furnishing extraordinary amounts of water, which might interfere seriously with construction; second, that in operation the bursting pressure from the water flowing inside might rupture the tunnel and establish objectionable leakage. There was possibility also of encountering ground difficult to grout and seal against leakage, if not kept within properly protected formations. As a matter of fact, the fear of heavy inflow of water was a very live one, and extra precautions were taken in that direction, a considerable plant being established for pumping purposes. No serious difficulties, however, were encountered in this direction except temporarily when a water-bearing seam was cut, which flooded the east shaft beyond the capacity of the pumps then in operation. Later, additions to the pumping equipment were made on a large scale as a guard against emergencies but no further difficulties were encountered.

The tunnel is finished with a solid concrete lining inside the granite walls averaging nearly 2 feet thick, and the joints in the rock back of it are filled with grout which was forced into them under pressure. The inside surface in contact with the water is smooth and the finished tunnel is 16 feet in diameter. The aqueduct waters thus pass down on the west side of the river to 1100 feet below sea level and up again on the east side, rising by steps in Breakneck mountain on the east to an elevation of about 400 feet above the river and at this level a tunnel passes through Breakneck mountain. The aqueduct then crosses the adjacent valley on the east side and thence through Bull hill on its way toward New York City, finally leaving the quadrangle a few miles east of Peekskill.

The Popping rock of Storm King. A more serious matter was presented by the strained condition of the granite encountered in certain zones in the shaft and tunnel. At some places the solid granite would pop off in slabs with a crackling sound and would sometimes fall quite without warning. These slabs came off quite independently of any rock structure, even breaking directly across the structure quite as well as any other way. Some of the slabs were thin and came to a sharp knife-edge. Injuries from falls of this kind were numerous and they became a serious menace to the workmen, who had to be protected by timbering or other methods.

At one place this popping became so active that the tunnel itself had to be protected from a sort of stoping process developed by this popping rock. Slabs had a habit of loosening and dropping off continuously. If the loosened ones were scaled off one day, new ones would be separated by the next. Thus the danger was a constant one. At this particular place stoping of this kind in the roof of the tunnel proceeded to such length that measures had to be taken to stop it by timbering. A steel support was finally installed at this point and was left in place when the tunnel was finished.

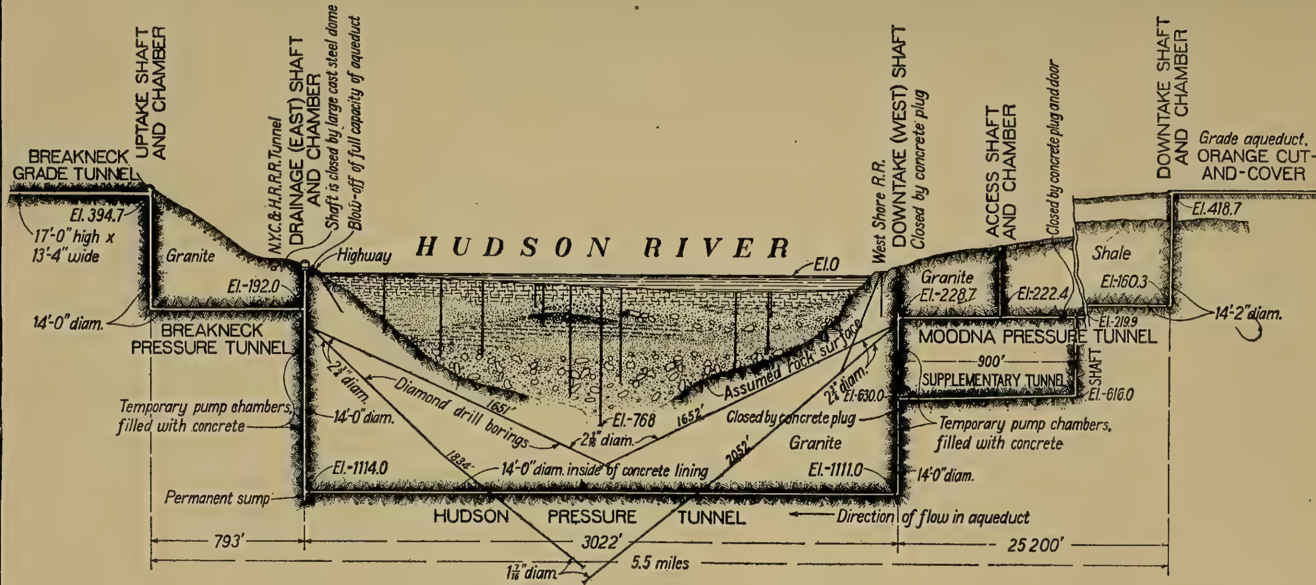
Even after the tunnel was finished, difficulty was made by this strained rock condition. When the tunnel was filled and put under operating pressure a pronounced leak developed on the Moodna side under Storm King mountain. Upon unwatering the tunnel the concrete lining at the Hudson river end of the Moodna pressure tunnel was found to be ruptured. Study of the possible causes led to the conclusion that rock strain aided by the bursting pressure of the aqueduct water was the cause, the tunnel at that point cutting through a strain zone at too shallow a depth to remain stable with the abnormal conditions then in control.

It was finally remedied by constructing a small portion of this end of the Moodna tunnel, where it joins the west shaft of the much deeper Hudson River pressure tunnel, at a greater depth in order to obtain more stable conditions and a better balance between bursting pressure aided by strained rock on the one hand and the load of rock above and its strength on the other. The corrected tunnel has since given no trouble.

A somewhat similar condition which was, however, corrected more simply, was developed also on the Breakneck side.

Bull Hill tunnel. Bull hill, or Mt Taurus, forms the second mountain ridge on the east side of the river toward the south and the aqueduct penetrates this from one side to the other at about 400 feet above sea level. The rock penetrated is of considerable variety in a minor way. But there is nothing beyond the complexities

Plate 48



CROSS-SECTION OF HUDSON RIVER CROSSING, LOOKING SOUTH. TOWARD WEST POINT

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belonging normally to the gneisses and granites already described in this bulletin, especially the Storm King granite and the gneisses associated with the Canada Hill type of granite which is more fully developed toward the south. Some of the complexities of relation and variety were beautifully exposed in this tunnel, but there was nothing of extraordinary interest or significance. All are covered at the present time with the usual concrete lining. No unusual engineering difficulties were encountered. The ground stood well and the work was prosecuted with no greater difficulty than in the average granite.

Foundry brook section. At Foundry brook, which occupies the depression immediately south of Bull Hill, the ground lies too low to carry the aqueduct at grade, and in the beginning explorations were made with the purpose of determining whether a pressure tunnel in rock could be constructed. It was finally decided to use steel pipe in crossing this valley, but the explorations that were made discovered certain conditions that are of general geologic interest and developed uncertainties which exerted an influence on the choice of plan finally adopted.

The usual heavy drift cover was encountered, but this in itself was not a serious matter. The condition that was considered more questionable was the discovery of a badly decayed condition of the crystalline rock, in one of the borings, to a depth of several hundred feet. At first, this was thought to indicate considerable extent of bad ground which might give much trouble in construction, especially as artesian or flowing water was furnished by one of the borings penetrating this zone. It was thought also that an old buried stream channel had been discovered that went to much greater depth than had been expected, but this was entirely disproved, and later explorations indicated that the decayed zone is probably very narrow and that it is in reality nothing more than a crush zone following a fault line along the east side of the mountain. The questionable boring passed through drift and then through a portion of the solid hanging-wall side of this crush zone for about 75 feet and then ran into the soft decayed rock of the crush zone, keeping within it from that point on to the bottom of the hole, probably bending out of its true course to keep within the softer ground.

No considerable trouble ought to be expected in such a zone in spite of the depth to which decay was found to extend. It would soon be passed through in a tunnel and would probably give no more difficulty in construction and in operation than any one of a large number of crush zones encountered at other points along the aqueduct line.

As a matter of fact, no unusual difficulties are presented for the construction of a tunnel at this point although at the time these facts were discovered there was less complete confidence in the success of pressure tunnels than came to be felt later. It is entirely probable that at some future time this link will be established in such form also, replacing the steel pipe by a pressure tunnel. An interesting thing in a geological way discovered by such explorations is the depth to which decay has reached in these crush zones and the support that it gives to the interpretation of the general structural habit of the district.

The artesian well damage claim. An interesting side issue drawn out of the explorations, and the condemnation of the ground on which the aqueduct is located, was developed at this point. The former owners of the ground where these borings were made, brought claim for extraordinary value when the land was condemned because of the taking of their artesian water supply. This flowing hole, discovered during exploration, furnished water which spouted out of the casing to a height of about 10 feet and it is, of course, excellent water. This ground was not known to carry artesian water before these explorations were made and it would probably never been discovered except for them. Nevertheless a claim was made for something like $75,000 because of the taking of this water supply which, it was held, has unusual purity and is capable of being placed on the market. The defense furnished by the city took the stand that this water-bearing crush zone doubtless continues for a considerable distance and extends into and across the residue of the property still remaining in the hands of the owners, and that it could be tapped by the same process of boring on the ground still retained. The theory was advanced that the water was carried by a crush zone extending for a long distance and was fed by the surface waters falling on the mountainsides farther up the valley. As these waters pass downward toward the river, where the surface is lower and where they are held in by a heavy overcapping of glacial drift which does not allow rapid dissipation, they can be tapped by boring into this underground supply which has all the structural characteristics of a certain form of artesian reservoir. This supply as a whole is not in the least interfered with by aqueduct construction as it was not allowed to enter the aqueduct. The boring already made was not only to be abandoned but could be completely sealed.

It forms a good illustration of the relation of geological factors to some of the side questions growing out of engineering undertakings. Numbers of such questions are encountered, some of which have even less foundation for special claim and it is not at all an easy matter to show what the real situation and relative responsibility is.

Garrison tunnel. After leaving Foundry brook, the Catskill aqueduct continues for some distance on the high ground with cut-and-cover construction along the sides of the ridges back of Garrison toward the south and enters a tunnel through the higher ridge which forms the divide between this drainage slope and Sprout brook. Although this ridge is not very high, a total distance of over 2 miles requires tunneling. This section is known as the Garrison tunnel. It cuts typical gneisses made up of remnants of Grenville and injections of granite and diorite, with all the complications characterising this belt. On the map this area is referred to the Canada Hill type because of the fact that this kind of granite seems to be the chief injection material and the largest single constituent. Parts of the belt carry two or three symbols indicating a mixed origin.

It is possible in this tunnel to study the minor structural features of the work in detail and get at something of the association of the different parts making up the average gneissic belt. It is possible also in this case to plot the jointing with a great degree of accuracy at great enough depth to be practically free from the influence of simple weathering effects. These factors have been plotted on the tunnel profile by the engineers in charge of this work and a typical section of this profile is reproduced as an illustration and a typical section of this profile will ultimately be made available through the final reports of the New York City Board of Water Supply.

None of these features, however, introduces any real problem in the engineering work. Interest from that side attaches to quite another matter, that of an excessive amount of decay of bedrock. At the north end of the tunnel for a distance of about 500 feet the ordinary gneisses forming the bedrock were found to be so completely decayed that the ground would not stand at all. In fact it stood no better than ordinary drift and in some places was much more difficult to keep from running into the tunnel. In this ground the structure of the gneiss was almost perfectly preserved, but the whole mass was soft and in places so completely leached of its quartz content that it could be cut with a knife or picked out with the fingers. The whole section of the tunnel had to be timbered right up to the very face of the workings, and the ground gave so much trouble that the work was slowed down and became more than usually expensive. It took the greatest ingenuity and care to carry on the work. Certain patches or streaks were hard, but these were not of sufficient prominence to dominate and materially influence the behavior for the first 500 feet. Substantial rock was entered at about that point and gave little trouble except at two or three crush zones where a badly decayed condition was encountered even at greater distance from the surface.

The special geologic interest which attaches to this occurrence is involved in the origin and distribution of this decayed rock. There is no good reason to conclude that such decay as this is postglacial simply from the fact that glacial drift lies immediately above it. As a matter of fact there must have been a very great deal of this kind of residuary material previous to the glacial erosion, most of which has been removed, and, after mixing with other materials, has become the drift soil. There is no reason, however, why certain protected places should not still preserve patches of such residuary matter. They are seldom seen, of course, because of the almost universal cover of drift, but in such a piece of work as the aqueduct where continuous trenching or tunneling was carried on across the whole district, numerous places were found where such decayed material is still to be seen in its natural position. It is common in crush or fault zones along which underground circulation is encouraged, and in a few places borings have discovered such a condition to a depth of several hundred feet. One such occurrence became of practical significance at Foundry brook, as noted under text head. Superficial material of the same sort is more seldom seen, and this exhibit at the north end of the Garrison tunnel is considered to be the best illustration yet discovered in this region.

The fact that exactly the same type of rock is perfectly fresh at other places both where it is fully exposed and also under drift cover is complete proof, all other conditions being essentially the same, that the decay is not postglacial. Otherwise decay of this sort would be much more general than it is. But if it is of preglacial origin, then there is no possibility of foretelling its development and extent, as it is directly related to the irregularities of quality and physical condition of the rock along which decay has been easy or difficult.

The fact that such material is occasionally encountered introduces an engineering factor, which, previous to these experiences, was generally overlooked. This is the possibility of encountering decayed rock of bad working quality, even after passing through the drift cover on high ground and in positions not usually considered questionable. As a matter of fact, good behavior was largely taken for granted in this case without much exploration, and it was only after encountering the difficult ground in actual construction that its quality became known. It is a striking thing in this case that the ground has a northwest exposure and it would appear that such a place high on the valley side should be completely denuded of such superficial material. That such is not the case, however, is a simple fact and it is not the only one discovered in a similar position.

Sprout brook valley section. At Sprout brook the aqueduct reaches a very narrow valley much too low for crossing without some special structure and too narrow to allow a very economical pressure tunnel plan in bedrock. Before the rock conditions were fully determined, however, explorations were made with the idea of determining whether the pressure tunnel method would be feasible. The rock floor was found at considerably greater depth than the present surface, the whole bottom of the valley being occupied by limestone standing practically on edge. Gneisses and granites occupy the sides of the valley and no unusual structural features were discovered.

As far as engineering requirements and working conditions are concerned, the rock tunnel is an entirely practical method. That plan was abandoned, however, in favor of steel pipe because of the more economical construction by that method. The tunnel would require a great depth of shaft at either side and that item thus becomes dominant in the total cost, being as great for this short structure as for a longer tunnel. This makes the cost of such a short section quite out of proportion to the other adjacent parts or equal lengths of other pressure tunnels. On the other hand, since the drift fill in the valley brings the floor up to 150 feet elevation, steel pipe could be used to practical advantage.

This is an especially good illustration, therefore, of the working of quite a different principle from that of geological interpretation or even of direct engineering questions in the matter of selection of design for a piece of work. The controlling factor in this case is relative cost.

Peekskill valley section. The aqueduct after tunneling through Cat hill reaches, at the western edge of Peekskill hollow, a much broader depression than Sprout brook, where again some pressure structure had to be selected. Explorations were made here also on a comparatively large scale to test the amount of drift cover, the rock profile of the valley and the quality of bedrock. These data, together with a drawing illustrating the suggested rock structure may be found in N. Y. State Mus. Bul. 146.

This valley is occupied by a down-faulted block of the Hudson River-Wappinger-Poughquag series crowded together so closely that the folds are essentially isoclinal and the beds stand on edge across the whole valley. Such a condition introduces no special difficulty in itself, but exploratory borings proved that in the limestone beds particularly the circulation of ground water has materially weakened the rock. Comparatively friable material was recovered in many places at considerable depth.

These explorations were made at a time before the interpretation of such conditions had become standardized by observation and comparison of the behavior of such ground in the tunnel construction. In the beginning there was much greater fear of the effect of certain natural conditions and less question of others than they have proved to deserve, and it took several years to put some of them in their true relation. In some places, therefore, where questionable conditions were encountered, an alternative design, wholly avoiding the question at issue, was adopted as the safest procedure.

This was doubtless the dominant factor in the decision to use steel pipe for the pressure section crossing Peekskill valley instead of the pressure tunnel in the rock, which could also have been constructed. It was also true that the steel pipe could be laid more cheaply in this section, but this was hardly the governing factor in this case. Those who have had much experience with the behavior in various tunnels since that time, and also had opportunity to check up on the original borings, know that borings are readily misinterpreted. Underground conditions are easily overemphasized or underestimated. It should be said, however, that as these qualities and behaviors have come to be better understood, the conviction has grown that a rock pressure tunnel would be entirely practicable in such ground as this. Perhaps tunnel construction will be resorted to at some future time if repairs or replacement of the pressure pipe should be required.

The Peekskill valley exploration, therefore, is of interest to the

Plate 49

Sprout Brook siphon of the Catskill aqueduct. The dump on the hillside is a spoil bank from the grade tunnel emerging at that point. A steel pipe makes the connection across the valley, and a cut-and-cover section then leads off to the left. The steel pipe is imbedded in concrete and the whole covered with earth.

geologist for two reasons: (1) it shows with accuracy the structure of this most interesting down-faulted block with quality and condition of rock that could otherwise not be determined, and (2) it illustrates an engineering problem where uncertainty in the interpretation of the conditions discovered led to the adoption of a new plan, avoiding the whole question.

HISTORICAL GEOLOGY

General Historical Outline

In the Adirondacks no formations are known older than the Grenville. This seems to be true also of southeastern New York, and there is no great doubt but that the formations designated as Grenville in these areas are essentially of the same age as those of the type areas in Canada. Unless this correlation is accepted, there is no possible way of determining even approximately the position of the oldest formations in this district with respect to the standard Precambrian system. On account of the very great similarity in character and the relations to other units, there is no serious doubt of the correctness of this name for the oldest metamorphic rocks of the district.

Grenville sedimentation. The series was sedimentary and undoubtedly of very large development. There must have been a basement on which these sediments were laid down, but thus far no trace of it has been detected. Probably the members of the series which are now found represent only a fraction of the whole series, presumably the uppermost members, and the igneous invasions have destroyed not only the basement, but also considerable portions of the original sedimentaries.

Judging from the quality of the formation still preserved, in which numerous limestones of varied prominence occur, the deposits must have developed under conditions favoring much shifting of sedimentation between lime deposits and clastic sediments. Perhaps they were marginal sea deposits into which the fluctuating streams brought much detrital matter. In which direction the land areas of that time lay, or what the general geographic distribution of land and sea was, is not indicated by the data now available. If, however, the Manhattan-Inwood series is considered as part of the Grenville, its heavy development toward the south would seem to indicate that the land areas probably lay to the west.

The largest development of limestone clearly belonging to the Grenville age occupies Sprout Brook valley and may be traced for several miles. Exactly how thick it is can not be determined, but it is at least several hundred feet. It fills the whole width of the valley at one of its widest points, fully a quarter of a mile wide, and, although folding may have caused considerable duplication of strata, it is difficult to avoid an estimate of more than 500 feet. The only other occurrence in the Highlands region comparable to it is the Franklin limestone in New Jersey which has a still greater development, perhaps more than 2000 feet. The only other limestone formation of similar size in the region is the Inwood limestone, farther south, which attains a thickness of at least 750 feet, and has a very extensive distribution from the Highlands to the sea. If the Manhattan-Inwood series is really of Grenville age, then this Sprout brook occurrence may be simply an outlier of the Inwood, as was assumed at one time by the senior author, and may thus represent the much sought extension of that series toward the north.

Although these two limestones may be traced to within a few miles of each other, their characteristics are so noncommittal that it is not considered fully proved that they are the same. There is no question, however, that the conditions of Grenville time were such as to favor occasional developments of limestone of great thickness, and it is also certain that shales and sandstones or arkoses and sediments of considerable variety were laid down in an apparently conformable series of great but undetermined thickness.

This must have occupied some part of Huronian time, a period of great sedimentary development. But the Huronian was a great complex and, in some regions, is represented by several series of formations with unconformities between them. To which of these the Grenville of this area belongs is quite unknown.

Grenville metamorphism. Subsequent history to the end of Precambrian time includes metamorphism, igneous intrusion, and erosion. Some of the steps are clear enough to warrant definite statement. Many others are so obscured by succeeding modifications that a complete history can not be unraveled from this region. Doubtless, however, a better history than we now present can be written when the full meaning of some of the confused structures and other criteria can be determined.

For example, it is still a point of great uncertainty how much of the extensive and profound metamorphism of certain formations is due to regional dynamic metamorphism rather than to contact influences, or whether it is possible by igneous intrusion alone to produce a recrystallization and a structural habit so nearly identical with

Plate 50

Typical banded, streaked, schistose, bedded, somewhat granitized and injected Grenville gneiss, showing the usual thin-bedded habit. The drag of a thrust fault parallel to the principal structure is shown also in the central foreground. The rock at the left side is considerably more granitized than is that with the more strongly bedded structure at the right.

that of typical regional metamorphism that they can not be distinguished. If, for example, this latter possibility will hold, then it may be that the Grenville did not pass through a period of regional metamorphism before its igneous history began. But if, on the contrary, igneous invasion alone will not accomplish this type of transformation, then it is necessary to make allowance for a greater period of time, and a whole epoch of dynamic and earlier history than would otherwise be necessary to assume.

The writers of this bulletin, appreciating fully the probability that igneous influences are capable of accomplishing profound results, and that in this district igneous phenomena and effects are much more prominent than dynamic effects, still hold that certain types of metamorphic phenomena are not exactly duplicated by igneous methods. We believe that strong schistose development of a series of rocks, with normal distribution and relation of minor structures, indicates dynamic metamorphism as the fundamental cause.

A closely folded series of strata with strongly schistose structure ought to furnish the conditions favorable to just the sort of effects produced by the later igneous history more successfully than rock in any other condition, and especially better than simple sediments essentially undisturbed. We regard it as practically certain, therefore, that the Grenville passed through a period of regional metamorphism and folding previous to its chief igneous history.

This period doubtless belongs to the Huronian also and it may very well be that a very great length of time even for Precambrian epochs has been covered. If the Manhattan-Inwood series is included with the Grenville it is all the more certain that dynamic metamorphism belongs to its earlier history, but the uncertainties of this series make it valueless as a point of argument on this question.

To accomplish regional metamorphism of the sort suggested would require that these strata lie under a load of other sediments, and thus a great sedimentation history preceding metamorphism is indicated. Metamorphism was, we believe, caused by folding which transformed the original sediments into foliated types; in short, a great variety of schists, phyllites, quartzites, graywackes and limestones. The structural character assumed in that period both in a large and small way has guided or at least has influenced all subsequent structural development. This folding was followed or perhaps accompanied by erosion, but whether the area was again the seat of sedimentation during the Precambrian is not indicated.

Some have thought that the Manhattan Inwood-Lowerre series are Precambrian sediments corresponding to this later point in the column, but, if they are not, then there is nothing known after the Grenville.

Post-Grenville volcanism. To this period belongs a complicated igneous history, and the results are so confused and overlapped that it is impossible to determine all the steps. It is clear that there has been repeated igneous intrusion. The largest and most fundamental step, however, was the development of a great granite bathylith which seems to have undermined a very large area of which this district is simply a small part. Its many successive stages of activity, accomplished most of the complexity of the Highlands region. Not all the igneous representatives are granite, however, and there is a wide range in the age of individual units; but the most reasonable conception, and the most important one for a working understanding of the history of the district as a whole, is that which connects the greater part of the igneous history with the normal development of a single great bathylith which was itself undergoing extensive changes for an exceedingly long time.

Probably the various individual units, distinguished now by their petrographic quality and which differed originally in capacity to metamorphose country rock, are essentially differentiates of the same plutonic mass. Perhaps one sees in such a regional occurrence an illustration of both recurrent activity and continued differentiation. In no other way can one feel justified in attempting to correlate the igneous formations of this district with those of such widely separated regions as northern New Jersey and the southern Adirondacks. It does not seem reasonable, otherwise, that in such a number of cases the petrographic habits would be similar enough in these separate districts to indicate identity and that they should match as perfectly as they do.

Igneous invasion in widely separated localities could not be expected to present so many points of similarity if there were not one control for all the districts. This control might very well be the successive differentiation stages of a single great bathylith from which the different igneous members came. If this conception is taken as a starting point, then the suggested correlations look reasonable enough, for a particular type of activity might develop in all the regions affected a similar igneous expression. After an epoch of comparative quiet, presumably with continued differentiation, a rejuvenation of activity might normally be expected to exhibit a similar expression again in whatever districts this new

Plate 51

Massive granite of the Canada Hill granite type exposed by excavation trench for a cut-and-cover stretch of the Catskill aqueduct at Continentalville. (Compare with plate 50 which is the commonest associated type). These are practically all gradations between the simple massive habit of this granite and the plainly bedded structure of the clearly distinguished Grenville sediments.

outbreak is found. Thus it might happen repeatedly, each time with some prospect of finding similar igneous behavior and to some degree similar petrographic quality in widely separated localities. Such a result, it seems, would be most unlikely without some sufficiently widely distributed, very fundamental, deep-seated single unit to be regarded as the chief manufacturer of the whole igneous history. Only on such a basis do we feel any confidence in suggesting the correlation referred to in detail in a later paragraph where the Canada Hill granite of this area is correlated with the Losee gneiss of New Jersey and with the older granite of the Adirondacks or when the Storm King granite of this area is correlated with the Byram gneiss of New Jersey and the Syenite series of the Adirondacks.

Such a genetic connection of the principal igneous members should develop the intimate mineralogic and structural gradations and confused and obscure transitions, which characterize many of these units, and it ought to yield a number of minor units of related origin, but with very great mineralogic differences. Such gradations and confusions ought to be expected, under the condition assumed, because the members are all of the same origin and form a genetic series between which there are no breaks beyond such as develop marginally during stages of quiescence or where successive individual apophyses invade country rock as separate units. All the older granite members, therefore, of this quadrangle seem to belong to a single igneous history and are simply the different expressions connected with the development of a single bathylith.

To this particular history belong the Canada Hill, the Reservoir, the Mahopac and the Storm King granites. Doubtless also some of the more basic rocks are of the same origin and represent extreme differentiates only. Even some of the magnetite bands or magnetite-bearing pegmatites are probably of the same connection.

It is not clear, however, that this is the very oldest igneous history. There are basic gneisses, essentially dioritic in composition, intimately associated with the Grenville that exhibit the schistose and gneissic structure more strikingly than most of the granites, and it is probable that certain of these dioritic units are older than the first granite. These may be referred to under the general term Pochuck diorite.

No good means of determining how much of a break there is between them has been discovered. The best evidence that we have is in connection with the Reservoir granite and the bands of dioritic gneiss developed in the vicinity of Peekskill and further to the northwest. It is clear in these cases that the Reservoir granite cuts the gneiss and also includes many xenolithic blocks of it, and it is clear also that these blocks had a complex structure before their inclusion in the granite mass.

It seems allowable, therefore, to postulate an igneous history of some sort earlier than the great granite invasion and to credit at least a part of the dioritic gneisses to this time. Acting on this evidence, in the tabulation of formations and in giving the succession of events, we have placed an igneous epoch with development of bases injections between the time of Grenville regional metamorphism and the great granite invasions.

Again at a later time, apparently after the great bathylithic mass had entirely ceased to function, there were igneous developments of a quite independent nature. One of these was the Cortlandt series of norites, gabbros and granites in the Peekskill vicinity, which probably belongs to a later period and not to the Precambrian at all. As a matter of fact, however, the age of the Cortlandt series is not known.

There are, however, smaller units of Precambrian age represented by dioritic and basaltic dikes, perhaps best referred to as basic dikes, which cut all of the formations up to the Cambrian. They are particularly abundant in the Storm King granite and associated gneisses. What relations these have to the larger series is quite unknown. They are clearly Precambrian since none of them cuts the Poughquag or Cambro-Ordovician series although they occur abundantly in the vicinity of the remnants of these formations. It is not beyond possibility, of course, that these dikes are representatives of the final stages of the same great bathylithic mass, but their strikingly different habit leaves that matter in complete uncertainty and the best that can be said is that they are much later and apparently independent.

A very extreme type of basic rock was found at one point in the quadrangle, essentially dunite. Only two specimens were gathered, both from the same occurrence, and the relation to the country rock is not very clear. Portions of the dunite are extremely sheared and deformed but beyond that there is no help toward a correlation.

There is undoubtedly still greater detail of Precambrian igneous history than is indicated in the outline above. Units have been seen in the field which are not readily matched with any of the fundamental ones which form the basis of this statement, but it is believed that they are in all cases incidental or minor developments

Granitized Grenville metamorphics and streaked Canada Hill granite cut by Storm King granite. An outcrop along the state road east of Breakneck ridge near the easterly margin of the Storm King granite intrusive.

The regular structured bedlike portion at the left is granitized Grenville in origin, the faintly streaked rcck making up most of the portion at the right, and in patches in the center at the hammer, are gneissoid Canada Hill granite, and the massive lighter portions, especially well developed in the central part of the outcrop, are Storm King granite.

or variants and that they are insignificant in comparison with the principal factors given. Whatever complexity of structure or quality they develop and whatever gradation or relative sharpness of relation they may show in the field they do not in any case materially conflict with the explanation given, nor do they suggest a definite modification of the history and principal stages.

Precambrian erosion. It would not be possible for the qualities of rock and the structures represented in this district to develop except at great depth. All the phenomena represented in the Precambrian, except that belonging to the original deposition of the sediments themselves, are of a deep-seated type. How deep, no one can tell, but probably many thousands of feet. What the surface expression was like, no one knows. There may have been and probably was volcanic activity, but all of this has been eliminated by the erosion which followed upon the completion of the igneous history.

Judging from the relations of the rock at the unconformity, between the Highlands series of gneisses and the Poughquag quartzite of Cambrian age, the region was worn down to a comparatively uniform surface. This surface is particularly smooth wherever exposed in this quadrangle and it would be allowable to assume that planation by erosion was very perfect and that essentially a peneplain was developed across the irregularities of the Precambrian series. This erosion cut down into the granite thus removing in many places all the overlying rocks and beveling across the representatives of every stage preceding. This may mean that a large amount of deformation accompanied the other transformations of the Precambrian history, both faulting and folding. But except for prominent shear zones, some of which appear to date back to this period, there is no other evidence beyond that exhibited by the unconformity just referred to. It is clear in any case that an immense length of time subsequent to the last igneous development must be represented in this erosion interval.

Cambro-Ordovician sedimentation. Whatever the conditions were under which erosion of the Precambrian series was completed, it is clear that sedimentation began with a clean swept floor on which remarkably pure quartz sands were developed. There is nowhere any development of conglomerate and nowhere much mixed or arkosic material such as might reasonably be expected from the erosion of a granite gneiss area. This fact makes one suspicious of the source of the material and the conditions under which these rocks developed. If developed from the gneisses and granites directly, no such formation could be accounted for without complete weathering of all rock and the removal of everything except the quartz. If done in this way it is difficult to account for the rounded condition of the grains and the extreme purity and the failure to find any conglomerate facies.

Perhaps the most consistent explanation is the assumption of an intermediate source, that is, a series of sedimentary formations, formerly covering the gneisses which has been destroyed in the making of the Poughquag and its associates. Such a formation, of course, if it carried sandstone or quartzite, would be capable of furnishing supplies consistent with the development of such formation as the Poughquag. The Manhattan-Inwood-Lowerre series might meet such conditions. It is particularly illuminating, therefore, to observe that the coarser members of the Hudson River series are made up chiefly of lithic grains instead of mineral fragments. In other words, the grains are largely complex rock fragments including fragments of slates, phyllites, schists, dolomites and quartzites. These are all fragments of some older somewhat metamorphosed sedimentary series which was largely destroyed to furnish the sediments of the Cambro-Ordovician. There is no escape from the conclusion that such modified sediments were available because the fragments can have no other interpretation.

The only question, of course, is whether any remnants of such a series are still to be seen. Unless the Manhattan-Inwood-Lowerre is such a series, there is no hope of finding it, but the series mentioned is quite competent to furnish just such supplies as are needed. The present exposures are more completely metamorphosed than are the grains found in the Hudson River series, but if one assumes that in Cambrian time only the uppermost members were exposed and that it was these portions which furnished the materials for the sediments, this discrepancy does not seem at all disturbing. It is entirely possible that there were sandstone members available from which the Poughquag supplies were derived. It ought to be expected also that the upper members of the Grenville floor, above the present igneous intrusions in which pegmatites are so prominent, had large developments of vein-quartz, representing the end products of igneous injection. This would furnish large amounts of additional quartz when these overlying rocks were destroyed.

Although there are few fossils, it appears that the Poughquag was laid down under marine conditions, for fragments of Trilobites have been found in this formation on the north margin of the Highlands. It appears also that the marine waters deepened and conditions of deposition changed to such a degree that a thousand feet of limestone was deposited, representing the Wappinger. Certain beds of this series carry marine fossils. Whether there is a break anywhere in the series does not appear in the rocks in this quadrangle, but whatever there may be is not a real unconformity because in all essential respects the series is conformable and continuous. Above the limestone an immense thickness of slates, graywackes and sandstones were developed which is known in this district as the Hudson River formation. The source of this material was undoubtedly some earlier series of somewhat metamorphosed sediments as already indicated. The deposition of this member, whose thickness is not known, must represent a shallowing of the sea and perhaps even occasional delta deposit conditions, but marine fossils are found in certain layers to the north and the structural behavior of the rock as a whole would lead one to suppose it to have been deposited under water and with good sorting.

Post-Ordovician revolution or deformation. At the close of the Cambro-Ordovician deposition the region was subjected to elevation and to the deformation of the Taconic epoch. Such a step would not be determinable, as a separate item, from the structural features of this quadrangle, but doubtless a part of the deformation which might otherwise be credited to the Appalachian stage belongs here. It is probable that the deformation of Taconic time has furnished, through subsequent erosion, the new supplies of sediments of mixed type for the great series of formations constituting the rest of the Paleozoic series. The Devonian bluestones and shales show chiefly lithic grains derived from some older somewhat metamorphosed formation, just as the Hudson River formation did before them. The fact that such grains were available indicates that these earlier formations, probably including the Hudson River, were enough metamorphosed at that time to furnish these grains of slates and phyllites and graywackes of which the Devonian beds are in large part composed.

Post-Ordovician erosion. Definite traces of this interval which is well marked a few miles farther north, are not determinable in this area. The best evidence of its existence are the qualities of material furnished to the succeeding formations as indicated in the paragraph above. It is entirely possible and indeed probable that great thicknesses of middle and later Paleozoic strata were formed on some of this ground. Many hundreds of feet of Devonian sediments still remain in a down-faulted remnant just to the west, forming Schunnemunk mountain. It is not reasonable to assume that such a great series stopped at this line. Indeed sediments of this type occur as down-faulted blocks in the Highlands, much farther to the southwest in New Jersey, but in this particular area no remnants are found inside the Highlands belt. That they once entirely covered the area may be assumed, and if they did, it simplifies very much the understanding of the behavior of some of the formations which show metamorphism and deformation inconsistent with any condition except development under considerable load.

Appalachian deformation. Mountain folding with much thrust faulting, is recorded abundantly in territory adjacent to this quadrangle in rocks of later age than the Taconic deformation. In this quadrangle, however, no later Palaeozoic rocks are preserved, so that the check on the time of the deformation epochs is inadequate.

Considering the quality of the later deformation, however, with its tendency to thrust faulting and the prominence of folding, it seems certain that some of the deformation of this area is of the same age as the Appalachian revolution. It is particularly difficult, however, to discriminate with certainty between this and the previous epoch. The tendency is to charge most of these features to the Appalachian deformation, and this is probably correct. The big thrust, for example, along the north margin of the Highlands on the northwest side of Storm King mountain and Breakneck ridge is a type of deformation that one would expect in connection with the Appalachian folding and faulting. The close crowding of the now down-faulted block, lying in Peekskill Hollow, is another that probably belongs to this period, and there are doubtless many others, especially those marking the strong northeast-southwest lines of weaknesses. What appears in these rocks as crush zones and longitudinal weaknesses may have appeared at the surface of that time as faults and folds.

It is probably not necessary to attempt a closer discrimination than this. It is certain that the Appalachian deformation is strongly represented and it is probable also that the chief weaknesses of the Highlands are connected with that dynamic event.

Post-Paleozoic time. No Mesozoic rocks are found in this quadrangle, but they are extensively represented in the quadrangle immediately adjacent on the southwest. The West Point quadrangle almost touches the northeastward extension of the great Triassic block of north-central New Jersey. It is entirely likely also that the Cortlandt series of intrusives belongs to Triassic time, although exact relations to the Triassic beds in this case are obscure, and the position of the Cortlandt series in the geologic scale is not definite.

The make-up of the basal conglomerate and other lower beds of the Triassic south of this quadrangle shows derivation from little modified rocks of Paleozoic age and indicates a very profound interval of readjustment and erosion. Probably part of the West Point quadrangle was covered with Triassic or later sediments of Mesozoic age which were later completely stripped by renewed erosion. The Triassic deposition was probably preceded and certainly accompanied and followed by great block faulting. Thus it happens that the northwest boundary of this Triassic area is formed by a great fault or series of faults, one of which is continued into this quadrangle as the west side of the Peekskill Hollow down-faulted block.

That there was some deformation in the early stages of the Triassic seems to be supported by the abrupt beginning of conglomerate made up of dominant limestone and quartzite pebbles undoubtedly derived from the exposed Hudson River-Wappinger-Poughquag series which at that time must have occupied adjacent Highlands ground. This period, therefore, was one of denudation of the area under study, but the sediments were not by any means the only source of material for the Triassic beds. Some of them at the base are very feldspathic and are very distinctly arkoses of disintegration origin without much decay. As development continued, however, alternating sandstones and shales accumulated with better sorting. They probably represent destruction of the Hudson River-Wappinger series as well as all the higher beds of Paleozoic Age which now came for the first time within reach of erosion. Thus it happens that the material furnished is of different quality from that found in the Hudson River shales proper or in the bluestones of the Catskills. Whatever of these later Paleozoic rocks may have rested on the Highlands district were also carried away.

Mesozoic faulting. By all means the most important development, still preserved in this quadrangle, belongs to that portion of Post-Paleozoic time known as Triassic and has to do chiefly with block faulting. How much of the total faulting of the district is of this age is again a matter impossible to determine in any considerable detail, except in certain lines. For example, that along Peekskill hollow enters the quadrangle at Tompkins cove, and has such a relation farther to the south as to indicate beyond question that it is a fault of this time. The one next farther to the west, which has prominent development along the Hudson river, following the Grenville belt, is undoubtedly similar in origin and age. It is not certain, of course, that the total deformation along these lines is of Mesozoic Age, but in some cases there is no doubt that a large amount of the displacement is Mesozoic. Many other fault lines have such uncritical relations that it is impossible to place them in a time scale, but it may well be that a good deal of the faulting traceable in the physiographic expression of this district belongs to this period instead of to earlier ones. At least it is certainly a mistake to credit even the bulk of the faulting to earlier periods. A more critical evaluation of the evidence doubtless will support the proposition that all the deformation periods developed faults and in some cases probably the same fault lines were the seat of new movement; but how much belongs to the different individual deformation epochs is not determinable.

The Mesozoic deformation, however, seems to have been of the nature of block faulting and is represented by little and wholly incidental crumpling or folding. Such an effect on a small scale might be due simply to slight crowding of the blocks. Faulting of the Appalachian time was dominantly of thrust type. That of the Taconic epoch is less definitely known and largely hypothetical, and those of earlier time are quite obscured by subsequent modification. The greatest prominence, therefore, might be expected to attach to the last two epochs and these might well be separated on the basis of character of deformation, that is whether, on the one hand, essentially a thrust with its accompanying adjustments or, on the other, essentially block faulting with little other distortion. This separation might be made more perfectly in some other kind of region than in one of granites and gneiss. In such formations as these, some of the evidences to be expected are either obscure or entirely lacking.

Most of the faulting belonging to the Mesozoic seems to have been of Triassic age. This is judged to be true chiefly because there is an obscure development of a peneplain on the gneisses of the Highlands. If much of the deformation were Post-Cretaceous, the peneplain ought to be interrupted and abruptly deformed. This does not seem to be prominent enough to warrant emphasis, but it may very well be that this is exactly the explanation for a curious discordance of peneplain level at the southerly margin of the Highlands. It seems as well established as any feature of this kind is anywhere that the top of the Palisade ridge from New York City to the vicinity of the Highlands on the west side of the Hudson coincides approximately with the Cretaceous peneplain. This rises very gradually from near sea level at New York City to a height of between 600 and 700 feet at Haverstraw. If this plane, which is fairly continuous and very definite, is projected to the Highlands across the Haverstraw-Stony Point lowland, it would strike the mountain mass of Dunderberg and Anthony's Nose and adjacent mountain masses much too low to correspond to any prominent physiographic feature on these mountainsides or elsewhere in the Highlands, except the ground near Peekskill and to the east and northeast of that point. The Cretaceous peneplain of the Highlands, if the tops of the mountains may be assumed to represent that feature roughly, is several hundred feet higher than the projected peneplain as thus traced toward the Highlands from the south, and it may be that the only meaning to be attached to this discrepancy is that some of the displacement along certain lines is of Post-Cretaceous Age.

The writers are inclined to believe that this is the proper explanation of the abrupt break in planes. Traced to the northeast, the discrepancy in levels fades out and there is no such additional movement suggested at all, for the weaker phyllites and limestones come in direct contact with granite and gneiss and are eroded to the same level along the contact without any physiographic expression whatever. Even the fault zone is not marked by any feature in most places. If there has been movement in Post-Cretaceous time along this fault, it is all confined to the extension of the line as it follows the edge of the Triassic fault block toward the southwest.

Yet another explanation has been suggested by the studies of Barrell [1] for the steplike arrangement of erosion planes in the northern Appalachians. He argues that advances of the sea have developed these forms as marginal and submarine planation effects in later Tertiary time. With this explanation the faulting or deformation question drops largely out of consideration as no deformation, beyond that accomplishing enough depression of the whole region to permit the sea to invade and enough re-elevation to cause its retreat, is necessary. Barrell seems to have substantiated his explanation in the region studied by him. We are not able to say, from the facts at our command in this particular area, the West Point quadrangle, whether or not marine encroachment should be accepted as the best explanation here.

Later Mesozoic overlap. It seems to be the belief of the physiographers who have studied the New England and New York region

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[1] Joseph Barrell, The Piedmont Terraces of the Northern Appalachians. Am. Jour. Sci. 49:257, 258, 327–362, 407–428. (1920)

that in late Cretaceous and Tertiary time there was overlapping far inland on the eroded surface by sediments belonging to the late Mesozoic periods. It is judged, for example, that the Hudson river itself has found its way toward the sea nearly in the particular position which it now occupies on such a sedimentary series of coastal plain deposits. If this is true, it was probably at the close of Cretaceous time that the Hudson river found its way across this territory, and continued erosion developed a tendency to a new peneplain level in late Tertiary time. Not long enough time or enough stability was maintained, however, to accomplish more than the beginning of such a plane in the widening of valleys and the development of flat bottom in accord with the new base level, while the divides reached up near to the former earlier Cretaceous peneplain.

At one stage at least a rejuvenation of the streams was inaugurated by a new elevation of the land and new trenches were cut into the bottom of these valleys. This was accomplished prior to the glacial period. It may be that this last step is more complicated than is suggested by the above statement. One of the evidences of a greater complexity is the occurrence of islands within the Hudson river gorge. It is explained in connection with them that the gorge was partly filled with new deposits, and then when the river was rejuvenated enough to cut down into them, it found itself entrenched in places along the side of the true former gorge in such manner as to be impossible for it to escape and slip over into the old position. It would necessarily thereafter develop a new gorge in that position which would ultimately become a part of the final completed Hudson river gorge. If projecting ledges were cut off in this manner on one side by the abnormally located river, and on the other side by the old channel of the river belonging to a preceding epoch, they would necessarily stand as islands in the gorge. It may be that this is the history of them; at least no better has yet been proposed.

During the late Tertiary, these physiographic details were produced and have become a part of the history of the region. The development of surface features as now represented, is the last stage in the history of the region and is regarded as the proper field of physiography. These features, therefore, will be discussed further under that head rather than at this point.

Glacial history. The region was subjected to ice invasion in the glacial period and seems to have been entirely covered with ice. Glacial erosion is evident as well as glacial deposits. The result of the glacial history has been in large part a subduing of the relief.

Postglacial changes are wholly of the nature of erosion. There has been some reelevation of the land so that terraces judged to date from the time of the recession of the ice are now lifted somewhat above sea level. On the rocks of such a region as this, however, and even on the type of glacial deposits represented, there is little modification produced in this time.

On account of the fact that the details of glacial history and in large part also of the late Tertiary history are bound up with the development of the physiography of the region, the rest of this discussion is included with the physiography.

Correlation Problems

Two entirely distinct problems of correlation are presented by the formations of this quadrangle.

1 One is concerned with the comparison of the Precambrian gneisses and granites, and the succession of events represented by these units in this district, with other districts where the succession may be either better known or have a somewhat clearer expression.

2 The other problem is concerned with the possible identity of the Hudson River-Wappinger-Poughquag series of Cambro-Ordovician sediments, extensively developed north of the Highlands, and the Manhattan-Inwood-Lowerre series of crystalline schists, marbles and quarzites south of the Highlands.

In the first problem, that of the gneisses and granites, the areas to be compared lie far apart and appear to be hopelessly separated from each other by intervening formations. In the second case, that of the Cambro-Ordovician correlation, representatives of the two series come within the bounds of this quadrangle and patches of the two contrasted series lie within a mile or two of each other. In neither case, however, can the problem be solved by tracing the one series directly into the other and, consequently, correlation must be based on comparison of major critical characters and similarity of history.

1 **The Precambrian gneisses and granites.** In this problem of the Precambrian gneisses and granites it is especially desirable to make comparison with the Adirondacks, where not only has a great amount of detailed work been done, but the geology is fairly well established in the same terms that have come into use in the much greater Precambrian fields of Canada.

Similar work has been done also within the Highlands belt in New Jersey, represented by the Franklin Furnace and the Raritan folios, U. S. G. S. Nos. 161 and 162.

The West Point quadrangle lies between these two representative areas, and if there is a definite determinable geologic succession, it would seem to be worth while to attempt a correlation of the principal members and match the major historical steps. In spite of the greater distance, such an attempt looks more promising for the Adirondacks than for the New Jersey area, chiefly because the succession of events has been more definitely determined there by long-continued work and perhaps the steps are more clearly indicated.

Comparison with the Adirondacks. In the southern Adirondacks, the essential items, following the later work of Kemp [2] and Alling [3] may be listed briefly as follows:

a The oldest member — the Grenville

This is made up of completely metamorphosed formational remnants of very complex original character, including limestones, shales and sandstones, with a complicated subsequent metamorphic and injection history.

Such a series is also represented in the West Point area, not on a very large scale, but with all the variety and complication usually assigned to the Grenville of other regions. It is here also, as in the Adirondacks, the most ancient member of the whole series and has had in general the kind of a history formulated for this formation by the Adirondack geologists. On the basis of essential identity of character, and relation to other members, the term *Grenville* has been used with the same meaning in this area. There appears to be no good ground for doubt about this correlation.

b The oldest intrusives — Laurentian

These are said to include meta-gabbro and granitic intrusions and injections which, together with the Grenville, are involved in and modified by all the other members.

This division is not so clear in the West Point quadrangle as it appears to be in the Adirondacks. But there are occurrences of similar habit in the area always appearing as injections of the Grenville or as gneissic products that appear to be older than the more definite simple granite units that make up the major part of the area. Some of these developments are moderately basic, giving a dioritic facies in many places. This is the Pochuck gneiss, in part, of the New Jersey geologists and the type seems to be very much better represented farther west than in the West Point Quadrangle.

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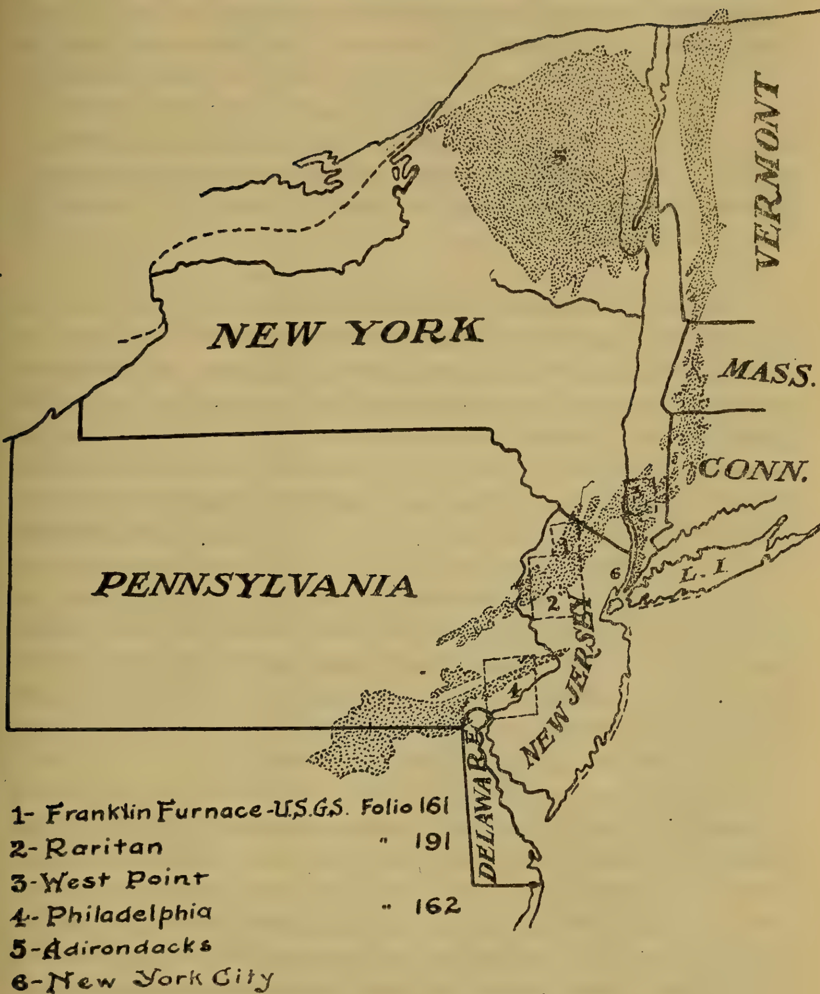
[2] Kemp, J. F. Geology of the Mount Marcy Quadrangle. N. Y. State Mus. Bul. (in press).

[3] Alling, H. L. Some Problems of the Adirondack Precambrian. Am. Jour. Sci. 48:47–68 (1919)

Plate 53



Key map of the principal Precambrian areas related to the Highlands of the Hudson, showing the relative positions of the available geologic folios

Its age relation is consistent also, as it seems to be the oldest of the large igneous members. A more pronounced development is of granitic character, such as the Canada Hill type. It is not at all clear, however, where the line should be drawn between the igneous representatives of this more ancient period and those of a later time. But taking the suggestion that these older ones are habitually more intimately intermixed with the Grenville so that they tend to form a series with close gradations and transitions, all of which also tend more strongly than do any of the others to exhibit a true gneissic structure, we believe that this member is represented in the West Point area also. Probably the Canada Hill type of this report is the chief representative (see the petrographic description).

c The principal igneous invasion — the *Algoman*

Represented in the Adirondack region by great intrusive masses of gabbro, granite, anorthosite and syenite. Of these, it appears that the gabbro is the earliest and the syenite the latest; but it does not appear that any great dynamic revolution or any marked historical hiatus separates them. The time represented is no doubt very long, but normal geologic evidences are largely lacking except for the fact that these igneous units cut each other and have a determinable succession. Some of the members of this division exhibit rather clear-cut and readily distinguished relations to the older series and even their minor injection phenomena tend to develop more striking lit-par-lit bands than were developed by the earlier invasions. They also are said to involve xenolithic masses of the older rocks in great profusion, but have not as a rule succeeded in destroying their identity or the evidences of their former character.

Perhaps the crux of the whole correlation problem, as far at least as it applies to the Adirondacks, is the possible identification of the members of this division in the West Point area. The most striking member, the anorthosite, is certainly not represented, and this is true also of the gabbro. But it is probable that the granite and the syenite or their close equivalents are represented by the Reservoir and Mahopac granite on one hand and by the Storm King granite, as the suggested equivalent of the Adirondacks syenite, on the other.

The Adirondacks syenite is the greatest of the field units of that region, showing much differentiation whose extent and behavior suggest a great bathylithic source and probability of much greater subsurface extent. It is the one member of this division, therefore, which would be expected to be represented in the Highlands if any occur there.

The different large units were compared with this member, with a good deal of care and with enough success to warrant the suggestion that the Storm King granite of the Highlands is practically identical in petrographic character and geologic position with the syenite of the Adirondacks.

d The younger intrusives — Keweenawan (?)

Occasional basic dikes ranging from camptonite to diorite and diabase are said to be characteristic of the Adirondacks, cutting all other formations. They are supposed to correspond in age to the Keeweenawan of the Lake Superior region.

Basic dikes of similar general composition and structural relation are also found in the Highlands. They cut the Storm King granite in numerous narrow irregular stringers quite independently of any of its primary or recent structures. These are essentially dioritic in composition, but others of slightly different habit and composition are found at other points. There is little doubt but that these correspond in all essential respects to those of the Adirondack region and the correlation is, therefore, satisfactory in respect to this division also.

e Metamorphics of obscure relation

These do not appear to be represented in the Adirondacks, but in the Highlands region a curiously obscure series of schists, crystalline limestones and quartzites exhibit such marked differences from the regular well-known Cambro-Ordovician sediments that it is difficult to escape the belief that they are really much older and properly belong to the Precambrian series. This is the essence of the problem of correlation referred to as the second item in the introductory statement at the head of this chapter, that is, the Hudson River-Wappinger-Poughquag comparison with the Manhattan-Inwood-Lowerre series.

This will be discussed under a separate head. All that need be said about it in this connection is that the lack of correspondence between the two districts, the Highlands and the Adirondacks, in this respect does not modify materially the identifications and correlations determined for the other members of the series already described. But it does introduce a problem of relative age which is of more than passing interest. For example, the very intimate association of certain igneous members with the Manhattan-Inwood-Lowerre series indicates that at least some of the granite invasions as well as some of the basic intrusives are in reality younger than this metamorphic series, so that if the age of this series could be determined, it would to that degree fix age limits to a certain amount of igneous history. Likewise, since this same series proves to be most intimately associated with the oldest gneiss, the Fordham gneiss in Westchester county and in New York City, where there seems to be conformity between them, the possibility of greater age for this series than is usually assumed is thereby suggested.

The questions raised, therefore, by the confused situation represented in the last item are: (1) Are some of the igneous members, both acid and basic ones, comparatively young, even late Paleozoic, as would seem to be indicated if the Manhattan-Inwood series is itself Cambro-Ordovician in age?, or (2) Is the Manhattan-Inwood series shown to be very ancient — perhaps a part of the Grenville itself — by the evidence of its roughly conformable relation to the oldest gneisses and by its igneous associations?

The enormous development of the Manhattan schist with its associated Inwood limestone south of the Highlands is of course most disconcerting, and if one assumes that they are of Grenville age, they certainly differ much from the typical Grenville of the Adirondacks and of the central Highlands belt. But they are not very unlike the Grenville of the typical Canadian occurrences. The chief difficulty therefore is not their character, but their sudden appearance, together with the fact that a very similar succession of sediments, the Hudson River slates, Wappinger limestone and Poughquag quartzite, of well-established Cambro-Ordovician age, are developed on even a greater scale only a short distance away. It is therefore somewhat easier to account for the difference in character by some metamorphic influences, which gave to the series south of the Highlands a greater complexity and more elaborate recrystallization, than it is to find a good structural explanation or reason for a great series like this one being so sharply delimited areally, and the failure to find any overlapping of the two contrasted series. A discussion of the points of the problem, however, in any greater detail is not in place here. (See a further continuation of the discussion on page 128.)

f The Precambrian erosion interval.

Both in the Highlands and in the Adirondacks, long erosion cutting deep into the metamorphic and igneous Precambrian series, preceded the Cambrian subsidence and deposition, and the first quartzitic sediments of that new order lie in strictly unconformable relation upon them.

Summary of the Highlands-Adirondack correlation. It is on the whole a very striking correspondence that one finds in comparing the Precambrian geology of the Highlands with that of the Adirondacks. Every large historical or sequence division of the more fully studied Adirondacks has been either identified or strongly suggested in the Highlands. This is all the more striking because the West Point area was studied quite independently of any such consideration, the whole series of formations and historical sequence having been formulated before any attempt was made at a critical comparison.

In the attempt to correlate the Precambrian of the Adirondacks and the Highlands, thin sections of some of the typical Adirondacks granites were studied. The granite-syenite series of the Adirondacks is very similar in most respects to the Storm King granite of West Point. The points in common are:

1 Medium coarse-grained texture.

2 Gneissoid structure.

3 Abundant microcline and microperthite, presence of pleochroic dark-green or brown hornblende, and (or) green slightly pleochroic pyroxene, and (or) brown biotite, as essential minerals.

4 Apatite, titanite, zircon and magnetite as accessories.

5 Comparatively low quartz content.

6 Absence of evidence of strong dynamic metamorphism, but strain shadows in quartz.

7 Rehealing of fine crush effects in feldspar with quartz.

They differ chiefly in the following respects:

1 The greater abundance of pyroxene in the Adirondacks syenite.

2 The greater alteration of the Adirondacks syenite.

The white Laurentian granite of the Adirondacks resembles the Canada Hill granite of the Highlands. Both have the same medium fine texture and granular structure, slightly gneissoid by reason of the orientation of the biotite. The essential minerals are quartz, orthoclase, oligoclase and biotite with slight microcline, microperthite and garnet. Garnet is more abundant in the Highlands.

The general appearance of the rock caused by the interlocking arrangement of the quartz and feldspars, the small lath-like crystals of brownish, bleached biotite containing rutile inclusions and the small faintly pink garnet are difficult to describe, but are very characteristic and readily recognized.

It is of course quite impossible under the conditions governing the present study to carry the correlation to great detail of identification or to complete certainty. The nature of the formations themselves, together with their history, impose rigid limitations also upon such a comparison; but it seems possible to affirm with considerable assurance that some of the individual members are represented in both districts by essentially identical units. Such identical members, for example, seem to be:

1 The *Grenville* metamorphic sediments:
Grenville of the Adirondacks-Grenville of the Highlands.

2 The *Injection granite* as well as basic injections, meta gabbros, etc. representatives of the older igneous series.
Meta gabbros and granite gneisses of the Adirondacks-Pochuck diorite gneiss and probably the Canada Hill granite of the Highlands.

3 The *Syenite* intrusive member of the younger series.
Syenite formation of the Adirondacks-Storm King granite and possibly Reservoir granite of the Highlands.

4 The later *basic dikes*.
Basic dikes of the Adirondacks-diorite dikes of the Highlands.

Comparison with the Franklin Furnace district in northern New Jersey. There is little doubt but that essentially the same series of Precambrian rocks as is represented in the West Point quadrangle extends indefinitely toward the south through northern New Jersey and into Pennsylvania; but it is not at all certain that correlation with the Adirondack types can be so fully determined for those more distant areas.

It thus happens that in the Franklin Furnace folio of New Jersey a very different set of terms and divisions are used, and a less definite outline of the historical sequence is indicated for them; but in a general way a certain similarity of history has been outlined for that district also. The following quotation[4] covers this point:

A comparison of the geology of the New Jersey Highlands with that of the Adirondacks and eastern Ontario reveals the fact that the Byram, Losee and Pochuck gneisses have their equivalents in the northern districts, and that in general the three districts are essentially similar.

The oldest rocks in the northern districts are crystalline limestones, quartzites and micaceous schists that are considered to be metamorphosed sediments. Beneath these and also interlayered with them are augite gneisses that may be mashed intrusive granites or the extreme phases of metamorphism

[4] Preliminary Account of the Geology of the Highlands in New Jersey; Bayley, W. S., Univ. of Ill. Bul., v. 6, no. 17, p. 18, Feb. 8, 1909.

of arkoses or acid volcanic tuffs. The complex is invaded by gabbros, and by rocks called syenites that are practically identical with the Byram gneiss in New Jersey.

The principal formations recognized by the geologists working in New Jersey are:

a The Franklin limestone (oldest) together with scattering remnants of metamorphosed sediments of other compositions such as quartzites and micaceous schists, representing the oldest series but mapped with other larger units.

b The Pochuck gneiss (next in age) a basic gneiss of very variable habit and probably both sedimentary and igneous origin. This is judged to correspond to the basic gneiss development of the West Point area, such as the belt at Peekskill, and to the meta gabbros and associated injection gneisses of the Adirondacks. This type is more pronounced in the Franklin Furnace area than in the West Point quadrangle.

c The Losee gneiss (apparently younger than the Pochuck). A series of very variable granite gneisses with gradational relations to almost everything else in the region. It is not certain that any of the formational units of the West Point area correspond very closely to the Losee of New Jersey; but perhaps the Canada Hill type represents the same general historical step.

b The Byram gneiss (the youngest member). This term covers a considerable variety of items according to the New Jersey geologists, but descriptions of its chief microscopic characters emphasize the constancy of certain mineral make-up and habit that suggest a possible relationship to the Storm King granite of the West Point area and the syenite of the Adirondacks. It is evident, however, if this correlation is correct, that the Byram gneiss formation is more confused in age and structural relation than are its equivalents farther north. Probably a closer correlation can not be made because of the different points of view of the different workers as to the chief formational distinctions and their significance.

Summary of the New Jersey correlation. The effort to correlate with the mapped districts of northern New Jersey has not been very successful. Doubtless the remnants of ancient sediments, now heavily metamorphosed and all but swallowed up in the igneous invasions, are the equivalent of the Grenville as used in this bulletin for similar remnants.

The Pochuck gneiss is probably also roughly equivalent to certain less prominently developed basic gneisses of the West Point quadrangle. The Losee gneiss is much more obscure and uncertain as to its equivalents and the Byram gneiss, although made to include a very wide range of expressions, as used in New Jersey, is probably in its simplest form a rough equivalent of the Storm King granite of the West Point area and the syenite of the Adirondacks.

In the West Point quadrangle it seemed at first preferable to assign the basic intrusives resembling the Pochuck to an intermediate position between the Canada Hill granite invasion and the Reservoir granite rather than to a period older than the Canada Hill. But later study favors the belief that these basic members have different age relations and that the principal basic type to which the name Pochuck gneiss ought to be attached is older than any of the important granites. The best representative is the occurrence referred to as the Peekskill diorite gneiss. In such case it may be that the dioritic-pegmatites and associated magnetites are connected with this member and are older than Canada Hill age.

Comparison with the New York City area. There is no doubt but that certain facies of the Fordham gneiss of the New York City district represent the Grenville. There is the same sedimentary origin evident in some of the beds, the clearest being numerous limestone layers. Most of them are not large, but they occur in such relation as to make their origin clear. The associated clastic siliceous beds are much more fully transformed and obscure than the limestones because they yielded much better to igneous injection and impregnation.

Examination of a collection of typical material from the Ravenswood grano-diorite of New York City (Brooklyn) shows resemblance in a few of the slides to the regular Storm King type of granite. The whole series with its wide range of mineral make-up is believed to be more consistent with the range said to be exhibited by the syenites of the Adirondacks. The Ravenswood agrees with both in one respect, that is, its apparent late appearance in the series of intrusives. In New York City it furnishes pegmatites which cut both the Inwood and the Manhattan and is itself a very vigorous invasion unit, developing elaborate injection and impregnation and syntectic effects. Perhaps to this latter habit is in large part due the great variety of composition shown in New York City although some of it may be due to actual differentiation.

Comparison with the Philadelphia area. The Baltimore gneiss of the Philadelphia area is regarded as the equivalent of the oldest gneisses of the West Point quadrangle and the Fordham gneiss of

New York City. An intrusive granite is described in United States Geological Survey folio 162 in terms that correspond very closely to the description of the Reservoir granites of this bulletin. The Wissahickon mica gneiss is doubtless the equivalent of the Manhattan schist of New York and the Octoraro schist of the Philadelphia region corresponds to the Hudson River slates and phyllites. In that district as in the New York there is an obscure structural relation which complicates the task of separating the chief mica schist from the younger slate-phyllite formation. The case is well stated by Doctor Bascom in United States Geological Survey Folio 162.

The problem of possible identity of the Manhattan-Inwood-Lowerre series and the Hudson River-Wappinger-Poughquag. This is the second big correlation problem presented by this area. These two series of rocks (the question of whether they are different is not raised at this point) are typically developed at the two diagonally opposite corners of the quadrangle. The Hudson River-Wappinger-Poughquag series constitutes a very small border along the north margin for a short distance and the Manhattan-Inwood Lowerre series has a much larger development in the southeast quarter of the quadrangle. Only one intermediate occurrence is found in this quadrangle and that is the phyllite-limestone-quartzite series which forms the down-faulted block stretching for many miles along Peekskill hollow.

This intermediate strip has often been referred to in discussions of this problem, and has been assumed by some to be the connecting link between the slightly metamorphosed series of the north margin and the very strongly metamorphosed series of the south side. These members of the intermediate belt do, as a matter of fact, show a somewhat more crystalline habit than the typical representatives of the north margin but a much less metamorphosed habit than the typical southern series. It is a rather simple matter to assume, therefore, that they form the true connecting link and that the very great petrographic and structural differences of the two series are the effects of a greater and greater metamorphism toward the south. The striking thing, of course, is the fact that this down-faulted block, although very near in position to representatives of the Manhattan-Inwood series, maintains its similarity to the Hudson River-Wappinger-Poughquag series so clearly as to leave no doubt of their identical age, and this in spite of the fact that they are many miles removed from each other in outcrop. On the contrary there is a very short distance between typical occurrences of Manhattan schist of the southern series and the phyllites of the Peekskill Valley. Nevertheless the two are strikingly different in petrographic quality. Since the present condition of both seems to be the result of regional metamorphism, it is very difficult for one to believe that such striking differences could be consistent with so short a distance.

Everyone who is familiar with this question has remarked how very different petrographically the two series are, and there is always the strongest inclination to consider them entirely distinct series. As soon as one begins a comparison, however, the difficulty of the whole problem is found to be much greater than was supposed, and a discussion of its essential points covers many other related features. It is such an important matter, however, in this particular area that it is necessary to go into this discussion with some care, and the following is a statement of the various points of evidence bearing on the correlation of these two apparently different series.

It is realized that the problem can not be solved in this quadrangle but that it probably can be solved by a careful round-about study of adjacent territory carried through for this particular purpose. Such a regional study does not fall within the scope of our present enterprise, but it is felt that a statement of the nature of the problem and the factors belonging to it will clarify the situation in this district and may be of service ultimately toward a complete solution of the matter of correlation.

Comparison of the two series. The argument can best be followed by arranging in parallel the two groups of factors believed to be essential and suggestive. First, for convenience, the factors that are considered to show identity of the two series; second, the factors that indicate independence of the two groups. Incidentally the study may serve as an illustration of the kind of problem usually presented in the correlation of obscure crystalline rocks.

Principal points of similarity.

1 The two series show great similarity in succession and original character and origin and in comparative thickness of the members. The upper member is made up of a great but indeterminate thickness of shales, sandstones, graywackes and slates on the north side of the Highlands and a strongly micaceous schist of usually very coarse and thoroughly crystalline habit but similar great thickness on the south side. The former represents the Hudson River shale series and the latter the so-called Manhattan mica schist (also called Hudson schist).

The next member below in each case is a limestone, varying from 600 or 700 feet to more than 1000 feet, the larger figure representing the Wappinger of the northern series and the smaller figure representing the Inwood of the southern series.

Beneath the limestone of the northern series is always a quartzite with a thickness of approximately 600 feet. Beneath the limestone of the southern series there is in some places a quartzite of very moderate thickness, not over 100 or 200 feet at a maximum, but this quartzite member is usually lacking. It is seen, therefore, that the two series are similar in succession and somewhat also in quality barring a great discrepancy in amount of metamorphism. In original condition they must have been strikingly similar.

2 In both cases the formation beneath the whole series is a complex of gneisses and granites, and in most places the exact relation to this underlying gneissic series is obscure.

3 Both series have been very much modified by deformation, so that the members are folded and sheared, and faulted in a very complex manner.

4 It is frequently stated that the sedimentary formations can be followed through the Highlands in New York, clearly connecting the two sides and proving them to be one formation. On the basis of such a statement workers in adjacent districts have assumed an identity of the two series which is not necessarily proved. As a matter of fact the nearest approach of the two series to each other is in the Peekskill valley and the adjacent ground just to the east, and even here the structural relations are so obscure that such a statement as this needs to be regarded with considerable caution.

5 Description of the variations in the Hudson River series north of the Highlands indicates that to the eastward, from the Hudson river toward the Green mountains or toward the Massachusetts line, the formation becomes gradually more and more crystalline until it exhibits all the petrographic complexity and peculiarity of the typical Manhattan schists of the south. This strikingly crystalline condition, in what is admitted to be the Hudson River series, removes one of the fundamental objections to its identity with the Manhattan. This objection is that along the Hudson river the wide difference of appearance is a strong support to actual difference in age. The crystalline behavior on the north side, however, toward the east, is not necessarily a proof of their identity because it may be conceived that the Hudson River formation, which is of similar original composition to the Manhattan, would become, under metamorphism, a rock of very like petrographic habit whether of the same age or not.

6 It is a very disconcerting structural fact that the crystalline series of the south stops abruptly on the Highlands margin, and although remnants of the Cambro-Ordovician series are found within a mile to the north, nowhere does one find clear evidence of an overlapping of these two series such as would be expected if they are of distinctly different age and separated by a long erosion interval. This would be understood readily enough if there was clear-cut evidence of great thrust faulting and very large displacements, but it is a difficult thing to explain considering the somewhat irregular outlines that are represented.

Principal points of dissimilarity and criteria indicating difference of age. The criteria given above would seem sufficient to satisfy almost anyone of the identity of the two formations. It is therefore rather surprising to find so many points of discrepancy and to find also that some of the objections are so difficult to explain away. The chief points of this character may be enumerated as follows:

1 There is a very striking difference in general physical appearance and petrographic habit of the different members of the two series, especially the upper member in each case. If one confines the discussion to representatives found within the quadrangle, the Hudson River-Wappinger-Poughquag series is strikingly less metamorphosed than the Manhattan-Inwood-Lowerre series of the south. Even if one considers fully the somewhat greater metamorphism of the down-faulted block of Peekskill hollow, the discrepancy still remains very striking, and no student of petrography would fail to discriminate between the phyllites of this locality and the Manhattan schists of Peekskill only a mile away.

2 There is a difference in thickness of certain of the members, especially an entire lack of quartzite in most occurrences of the Manhattan-Inwood series on the south side, as compared with the 600-foot thickness of the Poughquag of the other series on the north side. This is not an impossible condition of course, but it is rather surprising if the two are identical, especially in view of the fact that the 600-foot bed of quartzite still continues in the down-faulted block of Peekskill valley. Such a strongly developed member ought to occur much more extensively than it does south of the Highlands if the two series are the same.

3 The entire lack of bedding in the Manhattan member of the south side is in striking contrast with the rather frequently encountered strongly developed sandstone and graywacke beds of the Hudson River member of the north side. One would expect, even with

thorough metamorphism, that some of these sandstone beds would maintain their identity and be developed as graywackes or quartz-schists; but as far as the writer is aware, there is nothing approaching such a type on the south side. There are, to be sure, finer and coarser crystallization effects, some of which are very strikingly different, but the granular structural habit of sandstone or quartzite or graywacke is distinctly absent. To this degree, therefore, the two differ in a suggestive way in original quality as well as in metamorphism.

4 It appears very plainly in the series of the south side, especially in the Manhattan schist, that igneous injection, impregnation and intrusion is a strikingly prominent and widely distributed feature. Such an effect does not appear in the series of the north side within the district under observation or along the Hudson river. Such a difference might indicate different age, one older and one younger than a certain igneous invasion, but of course, it is possible that igneous invasion coming within reach of the members to the south did not reach those on the north side. Some observers have gone so far as to suggest that the difference in amount of metamorphism may be due not so much to the difference of age as to influence of the igneous invasion which caused extensive recrystallization of those portions south of the Highlands coming within its reach. It is an explanation well worth serious consideration and is along the line of argument recently put forward so ably by Barrell. All that one can say at this stage is that no sufficiently capable and new igneous member is known to which to credit this amount of change.

5 A striking difference of relation to the underlying gneiss series is observable in a few places. This structural discrepancy is the most insurmountable of the objections to the identity of these two series.

It is perfectly plain that the structures of the Cambro-Ordovician series and of the gneisses as observed on the north margin of the Highlands are entirely discordant. Undoubtedly after the gneisses were developed a very long period of erosion ensued and the basal quartzites represented by the Poughquag were laid down on that eroded floor. Considering the history of the gneisses as outlined elsewhere in this report, it is not surprising that their structures should stand nearly vertical and that the quartzite bedding should lie almost directly across this structure, as it does at certain places near the north margin of this quadrangle. The granites of Storm King and Breakneck do not break through into the overlying series.

Therefore, the unconformity is complete and as striking a thing as is to be found between any ancient crystalline series and later sediments.

On the south side opportunity is seldom found to inspect the intimate relations of the schist-limestone-quartzite series with the banded gneisses that lie below. Simple undisturbed beds are almost never seen exposed at the surface. In only two places may one see something of the structural relation, and these exposures are somewhat confused and obscured by erosion and cover. Neither of them lies within the quadrangle under discussion. One is at Ossining in the Tarrytown quadrangle and the other at Hastings in the Harlem quadrangle. Both show unusually good development of quartzite for the south side series, and as nearly as one may judge from the attitude of beds at the present time, it is conformable to the general structure of the gneisses. No better evidence than this of the relation on the south side is at hand, except as exposed in certain pieces of engineering work still farther to the south and east.

One of these is at Vahalla in the Tarrytown quadrangle where the surface drift was entirely stripped from the contact on the site of the new Kensico dam. Other occurrences are in New York City, in the Harlem sheet, in deep tunnels, one crossing the contact between gneiss and limestone under the Harlem river at 167th street, New York City, and the other under Delancey street in lower Manhattan, where the same relations were exposed in the city tunnel of the Catskill aqueduct. The striking thing about all three of these occurrences is the apparent conformity of the bedding in the Inwood limestone with the structure of the underlying gneisses, the quartzite being absent in all these places. Photographs have been taken of this contact and inspection has been made with great care. The best that can be said is that the structure is apparently conformable and, in the best occurrence of all, that under Delancey street, the structure is especially plain and the conformity practically perfect. In none of these cases is there deformation of sufficient consequence to obscure the relation and certainly no deformation of the usual sort could have brought about this parallelism of structure. It is difficult, to say the least, to find a satisfactory explanation for this apparent conformity other than the very obvious one that the beds are in reality conformable. One could readily believe that, in an occasional spot, the structure of the Precambrian rocks might accidentally coincide with that of the overlying series and be misleading, but it is past belief that all of them should be misleading.

It is true of course, that there is an elaborate deformation of the members south of the Highlands and that the principal deformation lines of different periods are parallel so that the later folding and faulting follow the general structure of the earlier periods. This tends to confuse the situation very much and, in places where a great deal of shearing took place, one might expect to find such a general parallelism of structure that most contacts would appear to be conformable. But one can not believe that the minor internal structure would be as consistent as it is on that hypothesis.

If one were to assume a later granite invasion involving the basal member of the Cambro-Ordovician series so as to form an injection gneiss out of the Poughquag quartzite, then one might conclude that the Fordham gneiss of New York City, with its apparent conformity with the Inwood limestone, is simply the injected Poughquag and not a Precambrian type at all. A comparison, however, of the gneisses of the Highlands and of New York City, especially those portions referred to as the Grenville in the Highlands, leaves no doubt but that the banded gneisses of New York City are precisely the same as the injection gneisses of the Highlands and that there is no room for serious consideration of the Poughquag injection theory. In other words, the gneisses of the two areas have similar history and there is no doubt that in major character they are essentially alike and should be regarded as identical.

This leaves the problem where it was before, with this structural dilemma. If the Hudson River-Wappinger and the Manhattan-Inwood series are the same, they must be unconformable with the gneisses in all the different occurrences and in that case the apparent conformity of the southerly series must be a deformation effect. But if, as appears to be the case, the southerly series is conformable, whereas the northerly one is strictly unconformable, then the two series can not be correlated and there must be a very great difference in age.

If one may assume for the moment that the southerly series is older and that it represents some of the most ancient sediments encountered in the district, then it would not be surprising to find that the basal members which were probably quartzose fragmentals in composition had yielded much more readily than the limestones to impregnation, injection and absorption by the invading granites. These lower members thus appear to have been completely transformed into gneisses and actually represent a part of the injected Grenville series. They contain numerous smaller beds of limestones which clearly indicate that in part the series is sedimentary, but they are so cut up and modified by igneous introduced substances that their former sedimentary habit is elsewhere almost completely destroyed.

Such selective effect involves an assumed control of injection by the quality of the invaded rock, as the limestones are not heavily injected or impregnated or even extensively silicated. This is true even of the small interbedded limestones in the Fordham formation. They are not usually badly enough affected to lose their identity in spite of the fact that they lie in the midst of large igneous injections. This can not be doubted for a moment if one has opportunity to inspect the whole series. If such selective control is true for the smaller members, it may very well be still more prominently exhibited by the Inwood. If the small members succeed in rejecting the invading matters, such a large member as the Inwood might very well escape without granitization at all and with only dikes and pegmatite veins cutting at random through it just as the formation now stands. It would seem to be possible, in other words, that members below the Lowerre might be so thoroughly invaded as to make all the complex gneiss structure that we have in New York City, while at the same time the overlying two members which give less encouragement to injection, might be as little transformed as the Inwood and Manhattan actually are. It is a most striking thing in this connection that the Manhattan schist is many times more affected by igneous matters than is the limestone which lies immediately below. Doubtless selective action of this kind is an important matter in the general process of injection and especially in that phase of it referred to as impregnation.

The striking thing is the evidence that seems to be furnished pointing to the possible Grenville age of the Manhattan-Inwood-Lowerre-Fordham series. In other words, if the Fordham is Grenville and the Inwood is conformable with and a continuation of it, and if the Manhattan is a normal succession after the Inwood, then there seems to be no escape from the conclusion that this whole series is Grenville and of Precambrian age.

It is most unusual that there should be doubt as to whether a formation is Grenville or Cambro-Ordovician, but there is such a doubt in this case.

6 A sixth point in support of the Grenville age of the southerly series is the fact that in two of the very best exposures, that under the Harlem river and the other under Delancey street, an interbedded layer of quartzose gneiss was encountered at some distance above the base of the Inwood. In one case, at Delancey street, the bed is only

4 or 5 feet thick and perhaps 10 or 15 feet above the base of the limestone. In the other case, the gneiss is farther removed from the base and is of greater thickness. In both cases, this interbedded gneiss shows injection effects and structure exactly similar to the gneisses which lie below the Inwood. No way of explaining these facts seems to be satisfying except that there is an actual transition of the sediments and we are inclined, therefore, to accept the extreme interpretation of the Manhattan-Inwood series and correlate it with the Grenville.

7 An additional item in the correlation of these sedimentary members has been gathered from a detailed petrographic study of the quality and source of their primary constituents. When this is applied to the Hudson River formation on the north side of the Highlands, especially in its coarser members, it is evident that the material was originally derived from still older somewhat metamorphosed sediments. Fragments of sandstones, slates, graywackes, phyllites, crystalline limestones and dolomites are present, and the quality of the material supports the hypothesis that the fragments were supplied by the disintegration of rocks of similar kind rather than directly from a granitic or gneissic type of country rock. It therefore appears that there must have been a series of somewhat metamorphosed sediments within reach of weathering agents at the time the Hudson River formation was being deposited. Remnants of such an earlier series ought to appear as an older more metamorphosed and more obscure series. Such a requirement is furnished by the Manhattan-Inwood-Lowerre series better than by any other formation yet proposed as a supply ground for the materials of the Hudson River formation. If this was not the supply, something else of like type must have been, and it seems much like begging the question to pass over a known thing for something of like character that is purely imaginary. It is realized, of course, that these arguments are not absolutely conclusive, for the fragments found in the Hudson River do not tally exactly with the present quality of the Manhattan-Inwood series; but, if one assumes that the higher and less profoundly metamorphosed portions of the series was eroded to furnish this supply, the materials ought to be similar to these fragments now found in the Hudson River beds. In short, they should not be expected to have as elaborate metamorphism as those portions of the Manhattan which were buried deeper and had opportunity for greater and longer continued modification.

8 It seems impossible to avoid the conclusion that the Manhattan-Inwood series has attained its petrographic and structural character under great load. Its metamorphism and deformation are such as to indicate reorganization under very heavy pressure. Something must have rested upon these members to develop the necessary pressure. The most violent deformation which one sees north of the Highlands has not developed such quality in the Hudson River formation. The chief failure in that case is doubtless not the composition and not lack of deformation influences, but chiefly lack of load or lack of special igneous influences or both. There was not sufficient pressure to cause complete reorganization. Perhaps also there was not sufficient time, but if the Manhattan-Inwood series is the same age as the Hudson River-Wappinger, the same limitation with respect to time would apply to it. If it is the same series as the Hudson River-Wappinger, then it is difficult to conceive of a sufficient load in the stratigraphic column represented to account for the metamorphism observed in the Manhattan. The schists are thoroughly recrystallized rather than sheared or granulated and have a prominent development of garnet and other typical reorganization products, all of which point to the same general conclusion.

Summary. The items enumerated and discussed on this correlation problem may be summarized as follows:

A Points favorable to the identity of the Hudson River-Wappinger-Poughquag and the Manhattan-Inwood-Lowerre series of sediments and metamorphosed sediments:

1 Similarity of succession and original character.

2 Occurrence of gneisses immediately below.

3 Both series much deformed and modified.

4 Near approach of outcrops of the two series so that one can be traced almost into the other.

5 Reported increase of metamorphism of the Hudson River formation toward the east, until near the Connecticut line it is practically identical in character with the Manhattan schist.

6 Failure of the structural relation that ought to be expected where the two series approach each other, especially the failure of either entire and actual unconformity or a simple transition.

B Points of dissimilarity which seem to support the hypothesis of different age and entire independence of the two series:

1 The strikingly different physical appearance and petro-

graphic habit of the two series, especially of the uppermost members.

2 General absence of the quartzite or lower member on the south side of the Highlands with the metamorphosed series.

3 Absence of as definite bedding and granular structure in the Manhattan as ought to be expected if it is the metamorphic equivalent of the Hudson River formation.

4 Prominence of igneous impregnation in the Manhattan and absence of igneous influence in the Hudson River formation.

5 Striking unconformity between the Poughquag and the gneisses on the north side, contrasted with the apparent conformity of the Inwood and the Fordham gneiss of the south side of the Highlands.

6 Occurrence of an interbedded layer of typical gneiss in the Inwood limestone member not far above its base.

7 The petrographic make-up of the Hudson River graywackes and other coarse-grained beds, which indicates derivation from the destruction of preexisting somewhat metamorphosed sediments rather than from gneisses and granites, and the fact that the Manhattan-Inwood-Lowerre series would meet the requirements of such a source better than any other now represented.

8 The evidence presented by the metamorphic condition of the Manhattan schist of a greater load of overlying sediments than would have been available if it is the equivalent of the Hudson River formation.

On the basis of these facts of observation and statement of relation it seems preferable to continue to regard these two series as distinct and separate and of very different age. The facts are stated in as unprejudiced a manner as possible rather than in the form of a completed argument, knowing that the problem will still be regarded as an unsettled one and that it will necessarily attract the attention of every worker on areal and structural geology in the crystallines of southeastern New York and adjacent districts. That additional data will be furnished from detailed study of neighboring areas is certain, and perhaps they will be more convincing than those listed above, but in any case a fair statement of the facts now available may be of service toward a final and more generally accepted solution.

General Correlation Table

	The Adirondacks	The West Point Quadrangle	Northern New Jersey	New York City and Westchester County	The Philadelphia Area
Cambro-ordovician (Sedimentary)	Canajoharie shale Little Falls dolomite Potsdam quartzite	Hudson River formation Wappinger limestone Poughquag quartzite	Martinsburg shale Kittatinny limestone Hardyston quartzite	Apparently not represented, although some authors place the Manhattan schist, Inwood limestone and Lowerre quartzite here	Octoraro schist Shenandoah limestone Chickies quartzite
GREAT UNCONFORMITY					
Post-Grenville—very old Precambrian: (Igneous)	Basic dikes	Basic dikes		Basic dikes	
(Later igneous)	Gabbro-Norite Granite Syenite Anorthosite	Pegmatites Storm King granite	Byram gneiss (a name given to a mixed product)	Pegmatites Yonkers gneissoid granite Pegmatites Ravenswood granodiorite	Pegmatites Granite Gabbro gneiss
Laurentian (?) (Igneous)	Granite Meta gabbro	Pegmatites Reservoir granite Canada Hill granite and associated injection gneiss	Losee gneiss (a name given to a mixed product)	Injection granites and pegmatites Fordham gneiss (in part) (injection gneiss)	Hornblende gneiss Baltimore gneiss (in part)
(Earliest igneous)	Hornblende schists derived from basic intrusions	Pegmatites and magnetites Occasional basic injections Peekskill diorite injection gneiss (Pochuck gneiss)	Magnetites and other ores Pochuck gneiss (a name given to a mixed product)	Occasional basic injections Staten Island serpentine Stevens Point serpentine The Hornblende schists	
Later Grenville (Sedimentary)	Apparently not represented	Manhattan schist Inwood limestone Lowerre quartzite	Franklin limestone	Manhattan schist Inwood limestone Lowerre quartzite	Wissahickon mica-gneiss (probably belongs here)
Older Grenville (Sedimentary)	Para-schists Para-gneisses Quartzites Arkosites Meta-limestones	Grenville metamorphics = Mica schists meta quartzites meta limestones (Sprout Brook limestone) para-gneisses (Fordham gneiss)	Metamorphic remnants chiefly variable schists and interbedded limestones	Interbedded limestones and schists Fordham gneiss (in part) (para gneiss)	Baltimore gneiss (in part) (para gneisses)
Keewatin (Chiefly igneous)	Probably some of the greenstones and amphibolites	Apparently not represented		Apparently not represented	

PHYSIOGRAPHY

Since the West Point quadrangle lies almost wholly in the Highlands, with crystalline rocks of various sorts making up its whole substructure, it does not furnish such complete illustration of the physiographic history characterizing the region as would an area containing a greater variety of rocks. The features are, of course, intimately related to those of adjacent districts where pronounced and critical physiographic features are represented.

Here as elsewhere the fundamental factor in the production of surface form is rock quality and geologic structure. It is, for example, due to the crystalline condition and resistant character of most of the rocks of this locality that the topography is so rugged and the surface elevated so much above the surrounding region. And ridgelike forms with their decided trend in a northeast-southwest orientation for both ridges and valleys result from the rock structure. It is also chiefly due to peculiarities of rock structure and lines of weakness caused by regional deformation that the valleys are narrow and that so many of them are straight.

Two structural conditions probably control nearly all the depressions. The most general is the occurrence of crush zones following fault lines; the other is the occurrence of belts of rock which are naturally less resistant to weathering and erosion than is the average country rock. The most pronounced of these latter are the limestone belts and next to them is the occurrence of Grenville rocks with their varied facies. It is very noticeable indeed that the only broad valleys in the whole district are developed either on limestones or on Grenville belts carrying occasional limestone bands

Other topographic expressions are related to glacial influences. Heavy deposits of glacial drift cover many depressions, and, in the southeast quarter of the quadrangle, the drift entirely obscures the rock floor topography and the detail of formational distribution and structure. Glacial lakes are common because of the filling of old outlets and the general obstruction of original drainage lines. Some of the accumulations are morainic and others are modified drift quite free from any other control than that of ice deposition.

Another feature that is somewhat independent of structure is related to the steps of physiographic history, represented by periods of peneplanation and rejuvenation. Thus it happens that there are plain traces of two attempts at base levelling and two or three periods of rejuvenation. Perhaps still other minor steps are represented which may account for some of the physiographic peculiarities.

Although a very elaborate statement of the physiographic history would not be warranted from a study of this district alone, yet the major steps of that history are represented by very definite features in the West Point quadrangle.

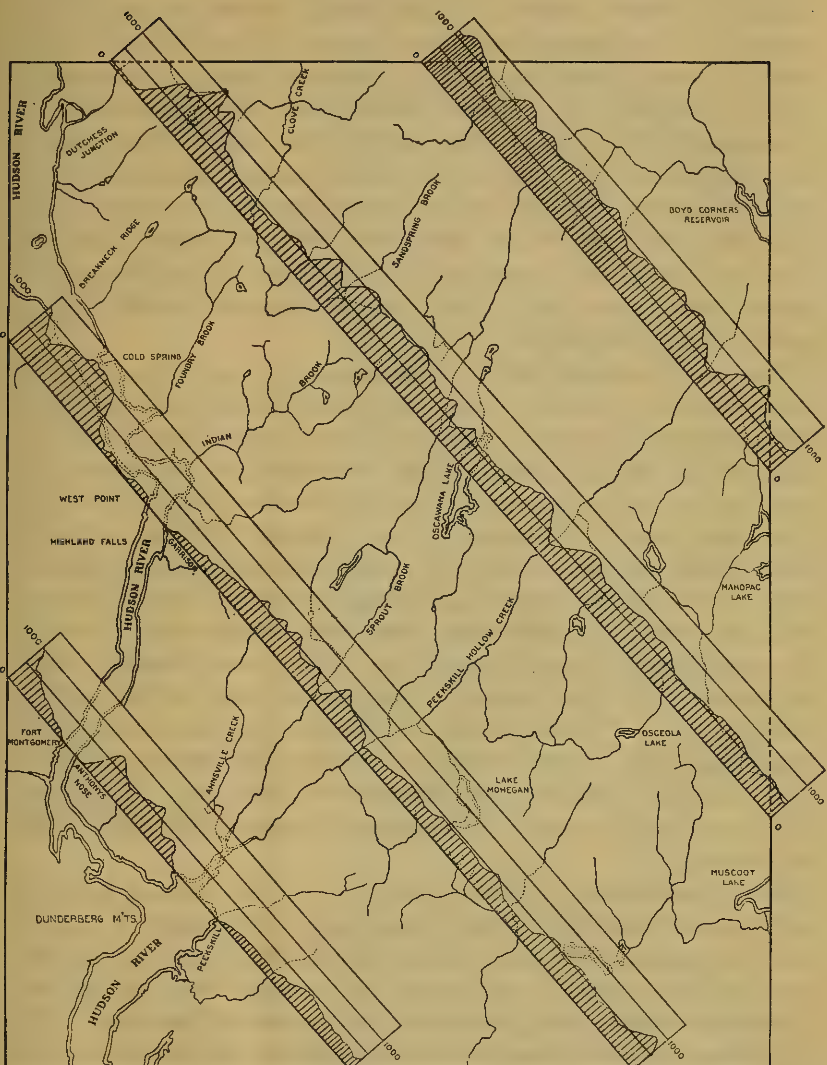
Cretaceous peneplanation. No upland portions of the area are level and the more elevated portions are far from any strict equality of level. Nevertheless it is true that the profile across the quadrangle on almost any line northwest-southeast gives heights for the principal ridges that fall into fair accordance. Occasional points rise above the average level and many fall below, yet it is very plain indeed that the average level rises rather uniformly toward the north and northeast. No doubt this would be still more uniform if it were not for large intrusions of massive granite which stand above the average level. Such cases are Dunderberg on the south and parts of the Storm King-Breakneck ridge on the north (plate 54).

From such profiles one is impressed with the fact that on the line from Garrison to Peekskill, the average elevation is not far from 500 feet. Five miles northeast a similar profile average gives something near to 900 feet and 4 miles farther, the general level runs about 1000 feet (see plate 51 which shows five profiles on a general outline map of the quadrangle). It is very striking indeed that on such a variety of rock quality there should be so uniform limitation of elevation. Perhaps this is due to the Cretaceous peneplanation. It is not probable that these levels already indicated correspond to the Cretaceous peneplain proper, although some of the higher levels may. It is very probable, however, that the Cretaceous peneplain in this region is indicated not by the highest point, but by the general level of the wider, more elevated portions. The irregularities appearing as depressions below that level represent erosion effects since that time.

Subsequent uplift is shown by erosion of the valleys, but in this region the valleys are all narrow and insignificant compared to those both north and south of the Highlands where the rocks are less resistant.

Tertiary base level. The Tertiary partial peneplanation seems to be very well marked indeed in the middle Hudson valley north of the Highlands reaching the extreme northwest corner of this sheet along the margin of Breakneck ridge where about 4 square miles of territory lie within the Great valley. No effect of this attempt at base levelling is to be seen in the gateway between Breakneck and Storm King and little evidence of it can be found

Plate 54



Profiles across the West Point quadrangle until the vicinity of Cold Spring, West Point and Constitution island are reached. From Cold Spring southward to Fort Montgomery prominent rock terraces on both sides of the river doubtless mark this Tertiary history. West Point is located in part on this terrace. A considerable area in the vicinity of Garrison and southward is on the terrace as well as Highland Falls on the opposite side of the river. It is rather striking that these terraces are so prominent in this portion of the valley whereas they are not apparent at all at the northern gateway or at the southern gateway between Dunderberg and Anthony's Nose. The reason for it, no doubt, is the fact that the rocks in this intervening belt are chiefly Grenville gneisses, schists and limestones, and on them erosion has accomplished much more than on the massive intrusive members represented at the other places.

The very decidedly different appearance of the valley walls in these different sections at first suggest the possibility that the river did not have its present course at all in Tertiary time at the two extremes of the gorge through the Highlands but did pursue the same course in the intermediate section between West Point and Fort Montgomery. Although it is not probable that such a change took place at this time it may very well be that the drainage immediately following the Cretaceous peneplanation was quite different from the present and that more prominent drainage than is carried at present came down through the Clove creek-Foundry brook depression, helping to develop a topography quite out of keeping with the present importance of the tributary stream draining this broad depression. In this middle section, the river follows the major rock structure perfectly, but elsewhere it does not. It appears, therefore, to be strictly a superimposed stream with only partial adjustment.

Minor oscillation. Physiographers have argued in favor of minor oscillation of level in addition to these major movements. It is plain that, subsequent to the mid-Tertiary base-levelling stage, a rejuvenation was inaugurated by uplift, and that trenches were cut into the somewhat widened valley bottoms by the streams of that time. This subordinate erosion stage has in most places in this quadrangle entirely obliterated all traces of the former base level, but in occasional stretches, as indicated above, terraces are still preserved.

It is possible, that other epochs of depression should also be noted in a complete history. If that is true, deposits ought to have been formed in the Hudson valley across this district, but no trace

A BLOCK DIAGRAM OF THE DISTRICT IN WHICH THE WEST POINT QUADRANGLE IS SITUATED SHOWING THE RELIEF FEATURES AND SOME OF THE CONTROLLING STRUCTURE

RELIEF DRAWING BY FREDERICK K. MORRIS—GEOLOGIC STRUCTURE BY CHARLES P. BERKEY.

of such material is to be seen now, and none is to be seen elsewhere north of the Highlands.

Certain islands within the present channel of the Hudson river, such as Constitution island, Iona island and several small ones, however, are believed to have a genetic connection with this missing history. It is argued, for example, that the river channel at first passed to the south of Iona island instead of the north side where it is now, and that this channel was established previous to one of these deposition epochs. During that time deposits were laid down filling the gorge, and when rejuvenated the river lodged on the opposite side of the valley from its former position, becoming entrenched there so firmly in the soft deposits that it has held that position ever since Even when the hard rock was reached it kept the new position and the islands have resulted from continued erosion. No better explanation has been given of the origin of several such islands in the Hudson gorge and no equally good structural reason independent of some such history is offered.

So far as the features of this quadrangle are concerned, therefore, little direct evidence of oscillation and former occupation of the ground by Tertiary deposits is to be seen, but the indirect evidence of the islands within the inner gorge is at least worth considering in support of such history.

Glacial modification. Glacial scour has accomplished more in the Hudson gorge than at most other places and perhaps some of the change of course as well as form is due to that agent. It has already been pointed out in connection with the discussion of the Storm King crossing of the Catskill aqueduct that glacial over-deepening and widening of the gorge has been proved at that point. It may very well be that glacial ice not only enlarged certain places which formerly were much more restricted, but that, at the time of withdrawal, it also left obstructing drift in portions of former channels that were previously open. Thus it may be that the change of course in the case of some of these islands is glacial and postglacial rather than Tertiary. The history at least with regard to some of these islands is obscured by glacial scour and glacial deposits and it may be that the position of the river is exactly reversed by this later experience quite independently of the earlier modifications. The present profile on such a spur as Anthony's Nose is good proof also of glacial modification of form. This prominent projecting mass has been snubbed by glacial ice.

No doubt the region was very elevated immediately preceding and during a part of glacial time. But beyond the fact that the river gorge is several hundred feet deeper than the present water level, no direct evidence on that point is obtainable. The region has since been depressed, however, somewhat lower than this former level. This is indicated by the fact that the river is drowned.

Postglacial changes. Evidence that the river level has changed since the time of the withdrawal of the ice is found in the occurrence of terraces of sand, gravel and associated delta and modified drift deposits at the mouths of certain streams emptying into the Hudson, such as Peekskill creek. The state camp at that point is located on one of these terraces which is just above the 100 foot contour. This agrees fairly well with evidence elsewhere that the difference of level since glacial time is something like 100 or 125 feet for this quadrangle. In the absence of other conclusive evidence to the contrary, it may be assumed that it means re-elevation of the land to that amount, the river representing sea level in each case. It is evident, from the behavior of the streams and their accumulations in these terrace materials, that the deposits must have been made during the withdrawal of the ice and while it was melting. In other words, they were furnished by the thawing ice. Therefore, they mark the immediate close of the ice occupation for this locality.

This may be taken as the starting point for postglacial history. Such erosion effects as have been accomplished on the drift are chiefly on the lighter modified drift types and especially on the river deposits which at one time may have largely filled the channel of the river at certain points. Reelevation rejuvenated the streams somewhat and they cut down through these silts and sands leaving the remnants as terraces. Farther back from the river and on more substantial types of drift and on bedrock few changes have been accomplished in this territory. The streams are all small and the modifications are limited to trenching soft deposits and cutting outlets a little deeper.

Some of the lakes of that time have been drained. This amount of elevation also emphasizes the islands in the river, some of which would be entirely beneath the water level if change of level had not set up new conditions. Even Constitution island would hardly be seen or little Stony Point or Iona island if it were not for postglacial reelevation and consequent readjustment of river level. None of the others would be seen at all.

The surface features of the area are therefore a combination resulting from the influence of many factors, some structural and petrographic represented by the different qualities of rock, some epeirogenic represented by uplift and depression, and still others by the very different effect of the agents, ice and water, under the changing limitations of different epochs. With the making of these forms the geologic history of the West Point area touches the present time.

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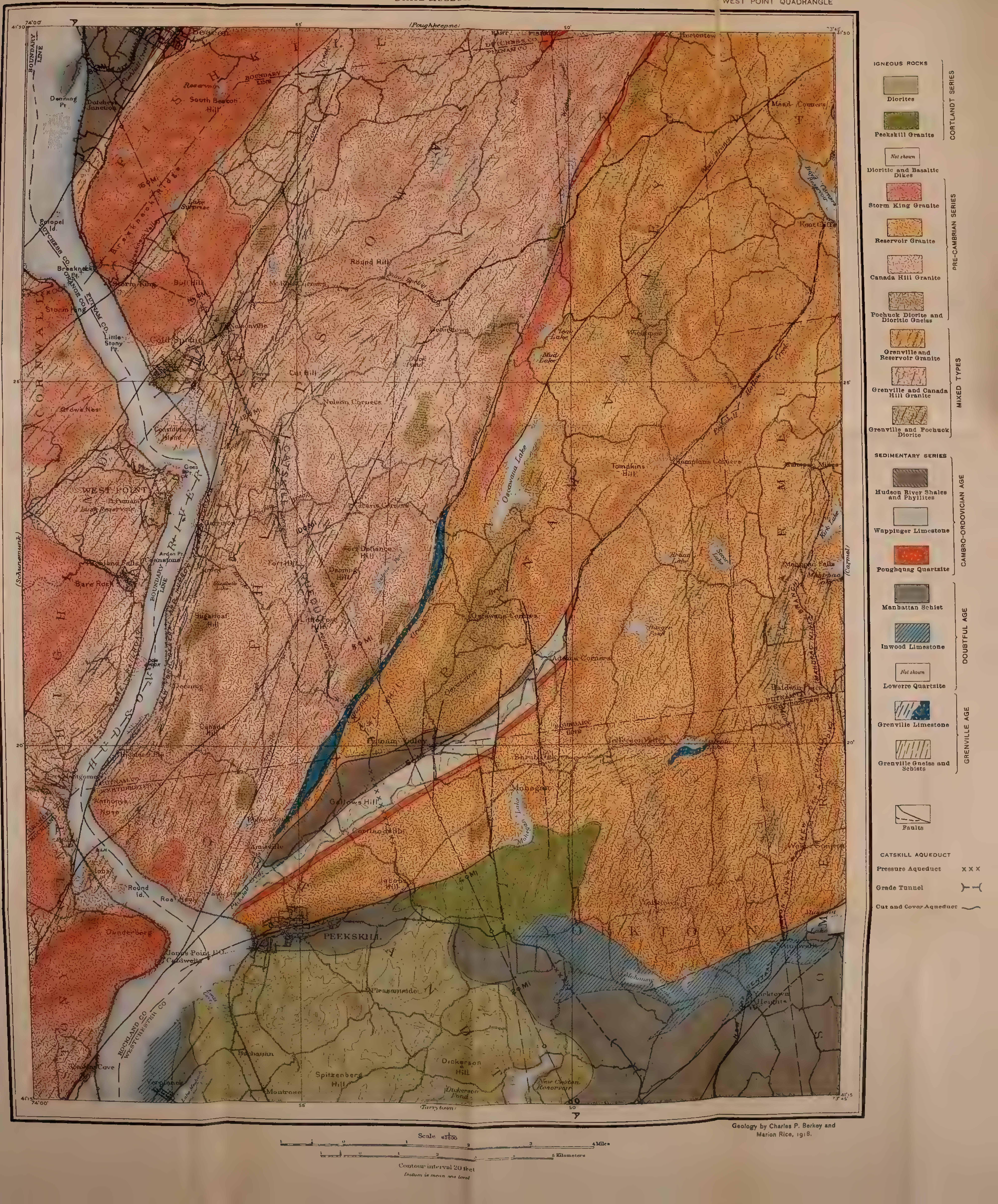

Geology by Charles P. Berkey and Marion Rice, 1918.

The Palisades of the Hudson
Haverstraw Bay
Dunderberg
Bear Mountain
Iona Island
Fort Montgomery
Highland Falls
Canada Hill
Anthony's Nose
Sugar Loaf

HUDSON RIVER-HIGHLANDS PANORAMA TAKEN FROM FORT HILL EAST OF GARRISON

Photograph by Wm. J. Bresnan, and used by permission of the New York City Board of Water Supply

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New York State Museum Bulletin

Entered as second-class matter November 27, 1915, at the Post Office at Albany, N. Y. under the act of August 24, 1912. Acceptance for mailing at special rate of postage provided for in section 1103, act of October 3, 1917, authorized July 19, 1918

Published monthly by The University of the State of New York

Nos. 227, 228 ALBANY, N. Y. NOVEMBER–DECEMBER 1919

The University of the State of New York

New York State Museum

JOHN M. CLARKE, Director

SIXTEENTH REPORT OF THE DIRECTOR OF THE STATE MUSEUM AND SCIENCE DEPARTMENT

INCLUDING THE SEVENTY-THIRD REPORT OF THE STATE MUSEUM, THE THIRTY-NINTH REPORT OF THE STATE GEOLOGIST AND THE REPORT OF THE STATE PALEONTOLOGIST FOR 1919

ALBANY

THE UNIVERSITY OF THE STATE OF NEW YORK

1921

M155r-D20-2600

THE UNIVERSITY OF THE STATE OF NEW YORK

Regents of the University

With years when terms expire

Revised to November 15, 1921

The University of the State of New York Science Department,
August 30, 1920

Dr John H. Finley
President of the University

SIR: I beg to transmit herewith my annual report as Director of this department and to request its publication as a bulletin of the State Museum.

Very respectfully yours

JOHN M. CLARKE
Director

Approved for publication

John H. Finley

President of the University

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INTRODUCTION

The work of this Department during the year past has suffered grave handicap from the difficulty of adjusting the income of the organization to the demands of the research divisions and the proper maintenance of the Museum. Inadequacy of compensation to the scientific employees has resulted in the loss of valuable men who have served loyally and sacrificed bravely but have at last reached the limit of resistance to the temptations of the industrial world. As long as the attachés of the scientific staff are without assurance of a decent living, are forced into situations where they must sacrifice even their Liberty Bonds to make ends meet, there must result not only a loss of the best service which can not be made good, but also a serious impairment of the spirit in which the work is done; a lessening of devotion and enthusiasm and a weakening of the bond of respect which the employee has toward the supreme employer. This relation between the State and its servants is, for this Department as doubtless for others, of the most serious concern for the efficiency of the organization.

REPORT

Geology. In pursuance of the plan for the completion of the geological map of the State on the scale of 5 miles to 1 inch, areal surveys have proceeded over several quadrangles.

In the Adirondacks region the Russell quadrangle has been covered by Dr William J. Miller and a report rendered thereon. The survey of the Lake Bonaparte quadrangle has been completed by Dr A. F. Buddington. The work upon the survey of the Mount Marcy and Ausable quadrangles has been concluded by Prof. James F. Kemp, aided by Harold L. Alling. The survey and mapping of the West Point quadrangle undertaken especially as a means of facilitating instruction in geology at the United States Military Academy has been carried through by Dr Charles P. Berkey, superintending the field work of Marion Rice. The report on the geology of the Gouverneur quadrangle by Prof. H. P. Cushing is completed.

All the reports listed above are in condition for publication.

Other geological activities have been a continuation of the examination and surveys of the postglacial deposits and drainage by Dr James H. Stoller in the Saratoga region, Harold L. Alling in Essex county and John H. Cook in Albany county, while Prof. H. L. Fairchild has been engaged with the special problem of the evolution of the upper Susquehanna valley, a work which it is hoped to extend to the entire course of the Susquehanna with the aid of the director of the Geological Survey of Pennsylvania.

Researches upon problems relating to the mineral industry which have engaged attention have been connected with the origin and composition of the salt deposits of the State, a work which has entailed a large amount of analytical examination for the purpose of acquiring more exact information regarding the potash and other minor contents of these deposits. Much of this work has been executed by Mr Alling under the supervision of David H. Newland, Assistant State Geologist. A restudy has also been made of the iron ores of Orange and Putnam counties by R. J. Colony of Columbia University.

Paleontology. In the category of special problems, Mr Hartnagel has prosecuted further study of the Clinton formation and fauna in central and western New York, which has been productive of interesting results both in paleontology and stratigraphy.

Doctor Ruedemann has advanced his investigations of the Lorraine fauna of the Ordovician and has now completed a revision of the formation and fauna in which are substantial additions to the

The road bed 3 miles north of Otisco, crossing an outcrop of Hamilton (Middle Devonian) shale. Every pebble shown in the picture is a fossil coral. Photograph by Dr W. J. Sinclair.

previous knowledge of the subject. It is hoped that it may be possible to publish this notable report in the near future.

In previous reports reference has been made to progress on the monograph of the Devonian crinoids. This extensive undertaking which has been carried forward by W. Goldring, has been completed. Its conclusion puts a period to an undertaking of long standing.

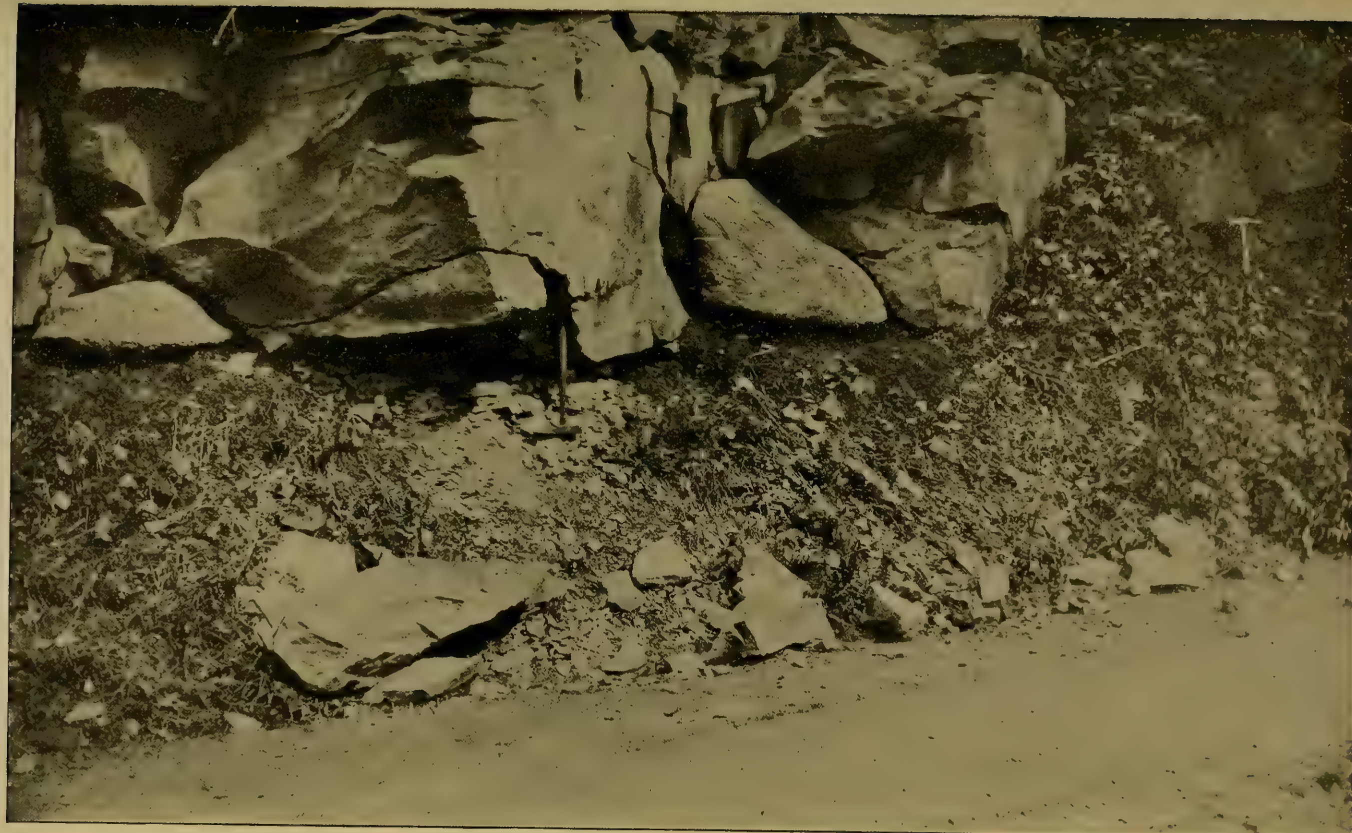
My last report contained the results of the examination of the Bonaventure cherts made by Dr Rufus M. Bagg and the results have been of such interest that Doctor Bagg has been asked to prosecute an investigation of the Devonian cherts of the Onondaga limestone with the purpose of determining the microscopic life contained therein.

Paleobotany. In all the history of paleontological investigation and collection in the State, fossil plants have been brought together quite incidentally to other investigations. Seldom has any special effort been made to search them out or to make a careful study of them. Notwithstanding, the Museum has by this desultory procedure come into possession of a very extensive and variant collection of the terrestrial plants of the Devonian period, a collection which has been authoritatively characterized as one of the largest assemblages known. Paleobotany is a phase of paleontology which has not received its share of attention in America and an understanding of the first terrestrial floras of the world has been restricted to a very small circle of students. This is a condition which has prevented the entry of this knowledge into the understanding of intelligent men, all the more regrettable as it is the branch of knowledge which has had to do with the beginnings of the whole world of plant life. The paucity of this knowledge and the intelligent requirement for more of it have led the Geology Division of the National Research Council to establish a committee on paleobotany in accordance with the purposes of which, as suggested above, provision has been made for a systematic pursuit of this field in this State. Several collectors are now in the field in search of this material and their efforts have thus far been attended with excellent results. A promising outcome of this work is indicated by the following account of the rediscovery of the fossil "fern" trees of Gilboa in the upper Schoharie valley.

The fossil trees of Schoharie county. A great autumn freshet in the upper valley of the Schoharie creek in 1869 tore out bridges, culverts and roadbeds around the little village of Gilboa and exposed in the bedrock of the hills a series of standing stumps of trees. These stumps stood all on the same level in the rocks and their rootlets ran down into the original mud in which they had grown, now turned into a dark or greenish shale. All had been cut off by some ancient flood at about 3 feet above the base; some were large and some smaller, the largest having a diameter in the shaft of 2 feet or more with broad expanding root-base like a flattened turnip. Thus was brought to light the standing remains of the most ancient forest growth known in the geological records in any part of the world. Ten of these tree stumps were taken out from their ancient forest, all at the same level in the rocks, and most of them were brought to the State Museum, where they have long constituted one of the remarkable exhibits of the vanished flora of the State.

The effort made this year to relocate this primeval forest of the Devonian Period or to find some additional evidence of its extent. has proved successful. The old locality is deeply covered and the rocks of that level which carried these trees do not come to the surface again in the vicinity. But the work has been attended with unexpected results in finding the stumps of other trees of the same sort at a level 60 feet higher in the rock beds, giving evidence that the forest growth had reappeared in the same region at a later stage in Devonian history.

The rediscovery of these primitive "ferns" is of very great interest from a scientific point of view. These trees are most nearly comparable to the tree ferns of existing tropical forests but no botanist would be content with this comparison, as they have a frutification quite unlike the spore-cases of the ferns, and the leaves were apparently narrow and straplike, branching simply and rarely and terminating in twin fruit cases. If the diameter of the trunks is carried upward in a tapering slope these trees must have reached a very considerable height of 20 to 30 feet, but it is possible that the trunks broke up not so far above their base into a shrubby or bushy cap. Their real nature is still a problem for the student of fossil plants. This will be disclosed in time but whatever the nature of this primitive forest growth may prove to be, they certainly afford an index to the geography of the western Catskills and the Schoharie valley during the late Devonian Period to which they belong. We have said that the tree stumps were found in places where they grew, that the shale under them are the muds in which they were rooted and that they are preserved at at least two levels in the rocks, one 60 feet above the other. Not far under the lowest forest the rocks carry true marine fossils. Tangled in the roots of the lower trees were found the remains of some brackish water animals. These facts of



Upper forest bed at Gilboa with tree trunks in place

Enlargement of one of the tree trunks in place

themselves show that the sea which covered this region slowly withdrew and the trees crept down from land to the water's edge, or grew over the delta plain of the fresh-water streams flowing in from the old land at the east. Then for a long time the first forest must have been flooded by the waters, probably by the rising of the sea which deposited the 60 feet of overlying rocks, until another retreat of the water again brought the forest down to the shore. There was an oscillation of the coast line, the sea rising and falling and the trees approaching, receding and approaching again toward the edge of the water. The story of the earth's primitive forest when fully written promises to be an interesting one, and it is hoped to reproduce, in part at least, in the State Museum, this picture out of the dim past.

It may be added to the foregoing " story " that these stumps when first found and recorded in the 18th report of the Museum, were studied by Sir William Dawson, then principal of McGill College and in his day the leading authority on the plants of the Devonian, and were regarded by him as probably " tree ferns," Psilophyton textilis, but present evidence indicates that they were also related to the cycad palms and probably are associated to the cycadofilices which were allies to both these groups. The location of the new series of stumps has been due to Herbert S. Woodward, who has had the assistance of Messrs Ruedemann and Hartnagel in the careful extraction of the remains and in the important discovery of the fruit cases.

Archeology. Excavations on Boughton Hill. Late in the summer of 1919 some field work was done on the historic Boughton Hill site in Ontario county. This site, which has been the scene of excavations and speculation on the part of antiquarians for more than a century, covers portions of the Green, Moore and McMahon farms in the town of Victor. The heart of the village seems to have been located on what is now a narrow strip 300 feet wide on the Moore farm. This strip was leased by the Museum and operations commenced on September 10th. It required but a few days of excavation to demonstrate that the site had been dug over for a period of many years and that but little remained for the systematic excavator to find. By persistent effort and by careful work twenty-five graves were discovered during a period of 30 days. The success of this search is due to the interest and conscientious labors of Everett R. Burmaster, who during a period of 15 years has acted as a field helper or as an advisor. The digging at Boughton Hill was difficult owing to the condition of the soil, which is a compact gravel-mixed clay. The difficulty was increased by the unsystematic excavations of amateurs whose filled-up prospects constituted false leads in many instances.

The Moore farm is divided into two general sections, the agricultural plot on the top of the hill, and the pasture plot on the west slope. The portion excavated in the autumn of 1919 was the brow of the hill in the pasture plot. Here on two lobate ridges running out into the brook valley, were found the burials. The specimens recovered include one bone comb, four clay pipes, a woven pouch, two wooden spoons, several strings of wampum beads and shell runtees. European material included glass beads, brass kettles, brass arrow points, gun locks and barrels, knives, chisels and punches. Of considerable interest are the specimens of dried foods, further preserved from decay in the ground by impregnation with copper salts derived from oxidation of brass kettles. These foods include apples, grapes, squash rind and seeds, pressed berries, corn bread and corn. Some tobacco leaf and " fine cut " Virginia is also among the preserved vegetable substances. Through substances such as these it is possible to determine some of the foods used by the Indians who lived at Boughton Hill.

The site is that known as Gandagora by the French. To the Indians it was Ga-on-sa-gaa-ah. This village was one of the great towns of the Seneca and was known to the colonists as early as 1637. During the conflict of the Iroquois with the French of Canada the village was attacked by Governor Denonville. With him were 1600 French soldiers, 800 of whom were trained men from France; the rest were hastily drilled habitants. To supplement this force there were some 1400 Indian allies, mostly Hurons and Ottawas. The Seneca occupants made several feeble efforts to defend their homes, but they were outnumbered ten to one. Fleeing before the superior invading force they abandoned and burned the village and fled to Gayaanduk, a fortified hill a half league to the west. This was almost immediately abandoned and burned, leaving the French and Indian invaders the task of destroying the corn fields and public storehouses. The French destroyed four principal villages of the Seneca and burned several small settlements, together with their corn fields and garden plots. A few Seneca Indians were killed but the Ottawa allies of the French accused Denonville of killing more horses and pigs than Seneca enemies. " You have destroyed the nest," said one Indian ally, " but you have left the hornets with their stings."

Antler spoon from a grave at Boughton Hill.
Excavated 1920.

Types of antler combs found at Boughton Hill, 1920

Antler combs found in graves at Boughton Hill, 1919–20

Antler combs found in graves at Boughton Hill, 1920

It was hoped that this important site might yield a large number of interesting remains that would shed light on the Denonville period of the Seneca. Our success during 1919 was sufficient to warrant an additional examination during May 1920. Operations were started on May 15th, the entire tract of land on the Moore farm being post holed. For the first two weeks little was found, but as the work started on the east side of the hill at a point that must have been the old stockade line, burials were found in numbers. Nearly two each day were unearthed. In all in the thirty-three graves there were found about fifty skeletons. The burials at this spot differed considerably from those on the west side, in that there were many disassociated remains. This may be due to several causes; first, the remains may be those of the slain after the battle; second, they may be the remnants of the house-burials; third, they may be the remains of those "buried" in trees and later taken down and thrown in burial pits.

In the east burial site European artifacts were numerous, the usual iron axes, copper and brass kettles and iron knives occurring in about the same proportion as on the west side. The articles of native manufacture found here include one antler spoon with a forklike end, four complete bone combs and three combs with broken teeth. A number of triangular arrow points were recovered, these being exceedingly rare as surface finds since the inhabitants had used guns for a generation before the destruction of their village. Beads of many kinds were found. Where possible they were restrung bead for bead as taken from the burial. In this manner we have restored several of these necklaces to their original condition. Of exceptional interest are the two pottery vessels found in graves. These were in a broken condition but it is hoped that they may be restored. Very few pottery fragments have been found on Boughton Hill and so far as we know none has been found in a complete condition, or even sets of restorable fragments. The type of pottery is a modified serrated or scalloped edge, of the Seneca or Neutral style of 1650. One pot has four perforated knobs that were evidently handles.

The interesting history of Boughton Hill and the character of the recoveries will make our two expeditions the subject of a larger and more complete report. It should be noted now, however, that the site was secured through lease by favor of Mrs F. F. Thompson of Canandaigua, to whom the Museum is indebted for many gifts and favors. The field experts this year were George E. Stevens and David B. Cook, both of Albany.

The Cornplanter Medal. The 1920 Cornplanter Medal was bestowed upon Mrs Mary Clark Thompson of Canandaigua in recognition of her numerous services in connection with movements related to archeology, ethnology and history. The medal was received for Mrs Thompson by the Director of the State Museum, who made an appropriate address.

The ceremonies of presentation are held under the auspices of the Cayuga County Historical Society of Auburn. The medal is given for notable services to the science of anthropology, to philanthropists who have given great benefits to the Iroquois, the historians, writers and artists, all of whom must have contributed to the knowledge or welfare of the Iroquois. Up to the present time three other persons associated with the State Museum have received the medal, William M. Beauchamp, Arthur C. Parker, Alvin H. Dewey.

The New York State Archeological Association. This organization, started four years ago, is flourishing and growing in numbers and enthusiasm. Its publications are popular and have had a considerable circulation. At present there are three organized chapters, one at Cooperstown, one at Rochester and one at Schenectady. The Rochester chapter has more than 250 members and gives a regular course of lectures, generally ten in number each season. Its annual banquets provide the means for a gathering of archeologists from all parts of the State. At the February 1920 meeting, Mr Langdon Gibson, president of the Mohawk Valley chapter, Schenectady, gave the principal address on " Tramping the Arctics with the Eskimo." A new chapter is under way in Syracuse and only awaits installation. It has been suggested that this chapter be named after William M. Beauchamp LL. D., the dean of archeologists in this State.

Activities of the New York State Indian Commission. At the beginning of this fiscal year the State Legislature created the New York State Indian Commission to be composed of members of the Legislature and certain representatives of state departments. The Governor selected the Archeologist of the Museum as the representative of the Education Department and at the organization meeting of the commission the Archeologist was elected secretary. In this way there has been no uncertain recognition of the ability of the State Museum to supply information relative to the Indian inhabitants of the State.

The commission has as its duty the study of the status of the New York tribal Indians and a subsequent conference with the committees of Congress relative to that statute. There is an apparent conflict of jurisdiction between the state and federal governments respecting Indian affairs. Beyond this the Indian tribes claim a certain independence and have asserted the right to regulate their own internal affairs. Certainly the Empire State can well afford to make a thorough study of this situation and provide the needed relief to these nations once so powerful as to be courted by the foreign powers that sought to colonize America.

The Indians chiefly affected by this commission are the Onondaga nation, near Syracuse; the Oneida tribe near Oneida; the St Regis Mohawks in Franklin county; the Tonawanda Seneca Band in Genesee and Erie counties, near Akron; the Tuscarora tribe, near Lewiston, Niagara county; the Seneca Nation on two reservations, one near Gowanda and one near Salamanca.

Each tribe has a somewhat different status but all are regarded as wards of the federal government and all fall under the provisions of the Pickering treaty of 1794–95. This treaty pledges the Indians immunity from disturbance and interference in the possession of their lands. While the Indians are regarded as " wards " we have not been told when they became wards or how, for when the treaties were drawn these Indians were regarded as competent contracting parties. Somewhat later they were denominated wards. If they are wards of the federal government the question arises as to what right the State has to legislate for them and how it can force the Indians on their several reservations to obey state law. The government has been disposed to let the State care for the Indians in the matter of schools, highways, enforcing the sanitary code, and in cases of the poor and indigent. There is now some question as to the right of the State to do this, though the moral propriety of the fact is not impeached. The Indian Commission is charged with the task of bringing about a well-understood status and in eliminating the causes of dissatisfaction and the barriers to progress. If the Museum through its department of archeology can be of assistance in clearing up this vexatious problem that has troubled the administration of Indian affairs in this State for so many years it will be felt that a practical good has been accomplished.

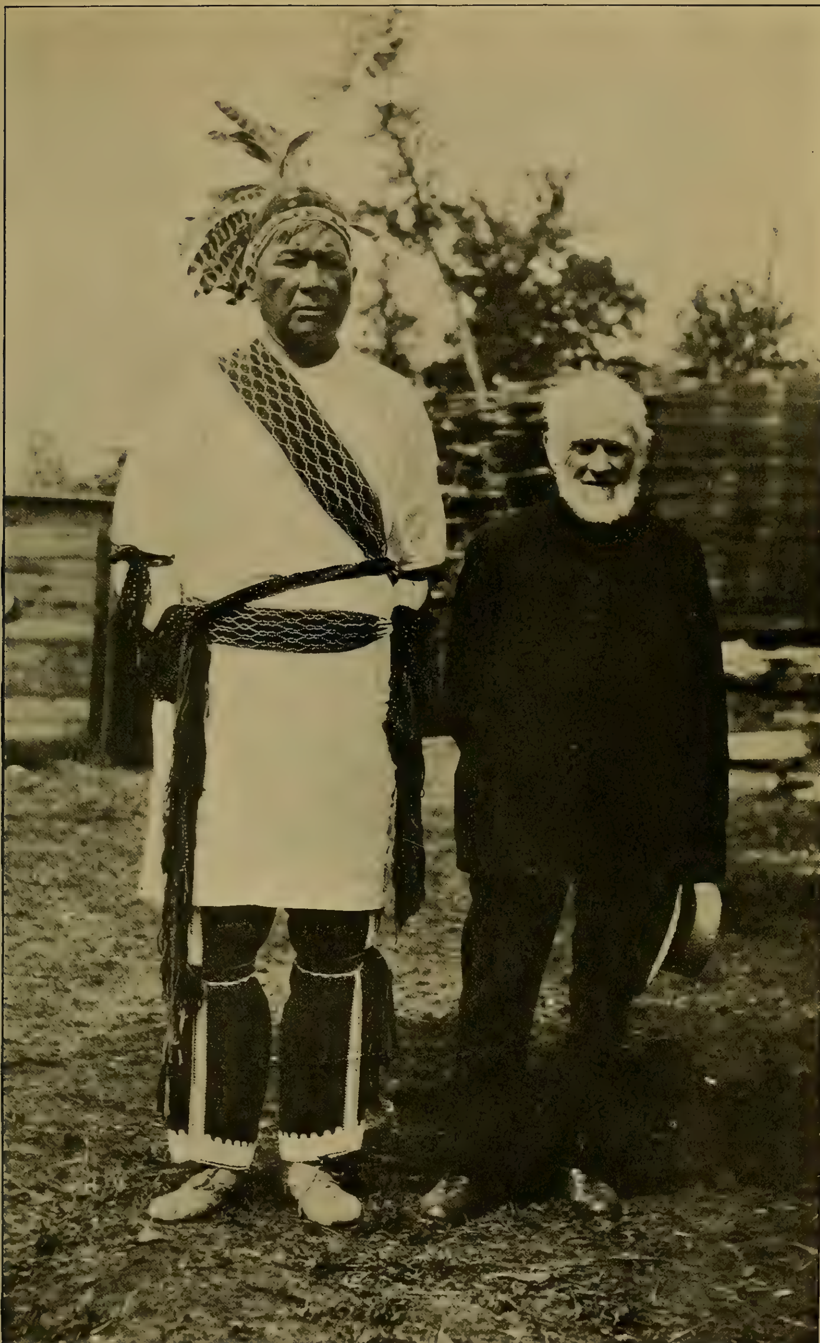
The members of this Commission are Assemblyman E. A. Everett, chairman; Senator Loring F. Black, vice chairman; Speaker Thaddeus C. Sweet, J. Henry Walters, De Hart H. Ames, Attorney General Charles D. Newton, Charles D. Donahue, Peter McArdle, Dr Robert W. Hill, Dr Matthias Nicholl jr, Chief David R. Hill, Arthur C. Parker, secretary.

New York Indian Welfare Society. During the month of May a general call was issued to the Indians of this State and their friends calling them into a general conference for the purpose of discussing their present and future needs. The meeting was held May 11th in the Historical Society Building in Syracuse and on the 12th at the Onondaga Council House. For the first time in many years Indians of all classes and schools of thought met in joint conference. The temporary chairman was Jesse Lyon, the courier of the Six Nations. Mr Lyon is a stalwart exponent of the old régime and is bitterly opposed to citizenship, preferring the citizenship of his tribe to that of the United States. After a vigorous session in which each division explained its beliefs, an election was held. The officers selected are: A. C. Parker, president; Dr Louis Bruce, a St Regis Mohawk, treasurer; David Hill, an Onondaga, secretary. The vice presidents are: George Thomas, Onondaga; Nicodemus Billy, Tonawanda; Alexander Burning, Oneida; Delos Kettle, Seneca. The councilors are: Jesse Lyon, Onondaga; Moses White, St Regis; Howard Gansworth, Tuscarora; Rolling Thunders, St Regis. There is also an advisory board composed of two sections; the section of the last conference and the section of the future conference. Dr William M. Beauchamp is chairman of the Syracuse section and Alvin H. Dewey, chairman of the Rochester section. The Rochester meeting will be held November 11, 1920 under the auspices of Morgan chapter of the New York State Archeological Association. This organization was conceived by Dr Earl E. Bates of Syracuse, who is the honorary president.

At the Syracuse meeting in May there were present representatives of the State Indian Commission, including Chairman E. A. Everett, David R. Hill and Dr Robert W. Hill. The Friends Indian School of Tunesassa was represented by William A. Rhoads, superintendent, and Henry Leeds, missionary.

Wild Flowers. The "Wild Flowers of New York" has been completed and published. This quarto work in two volumes has engaged the attention of the State Botanist for five years and has been progressed and brought to conclusion in spite of great difficulties growing out of the war and its consequences. The beauty of the execution of this work is greatly to the credit of all who have had a part in its making and it is confidently believed that it will render an excellent service in disseminating a knowledge of the native flora of the State.

Living Mollusca. For many years as time has permitted, there has been in preparation an illustrated report on the Mollusca of the



Delos Big Kettle (Sai-no-wa), a Seneca chief, and the Rev. William M. Beauchamp (aged 92), for many years author of and contributor to State Museum bulletins on Indian subjects.

State by Dr Henry A. Pilsbry of the Philadelphia Academy of Natural Sciences, the recognized leading authority in this field. This work is now practically complete and it will be offered for publication in the hope of reviving among our people the interest in the "belle science" which was so keenly alive a half century ago.

BOTANY

The work of the State Botanist's office during the year ending July 1, 1920, has been largely a continuation of lines of investigation and routine previously reported upon.

Field investigations. During the latter part of the season of 1919 there was carried on a continuation of botanical field work in the lake region of central New York, particularly about Oneida lake, and the region immediately to the east of that body of water. Several species of plants and fungi previously unknown to that region were found and added to the state herbarium. Particular attention was given to those fungi known as plant rusts.

A few days during May 1920 were also spent in the same region, resulting in additional knowledge regarding the early spring vegetation of that region.

In late June, four days were spent at Lake Bonaparte, northern Lewis county, supplementing field work during early June of 1919, at the same place. The results of these field investigations will appear in the reports of the State Botanist for 1919 and 1920.

Ferns and flowering plants of New York State. A complete list of the ferns and flowering plants of this State which has been in course of preparation for some time has nearly reached completion. This list gives the scientific and popular name of every species known to occur within the boundaries of the State, the comparative abundance of each one, and in case of those species which are rare, local or very uncommon, the previously published notices of them are cited, and definite reference to authentically determined specimens in the leading herbaria are added. Similar lists have been published upon the flora of New Jersey, Connecticut and other states and have fulfilled a long felt demand upon the part of those interested in the vegetation of these states, both from a popular and from a scientific point of view.

Determinations. During the six months ending July 1, 1920, the State Botanist's office has been called upon to determine 165 specimens of plants (including fungi and ferns). These determinations were made for 47 persons, only six of which were from outside the State.

State herbarium. Continued curatorial work on the collections has resulted in bringing the large assemblage of fungi, mosses, lichens, ferns and flowering plants into an improved systematic arrangement.

In addition to assembling the current collections for incorporation into the herbarium, a large amount of unmounted material has been brought together and is in process of being mounted by competent temporary assistance, beginning June 15, 1920.

ENTOMOLOGY

The Entomologist reports that the season of 1919 was made noteworthy in entomological annals by the discovery in late January of the European corn borer at Scotia, Schenectady county. The infestation was found subsequently to include portions of Albany, Schenectady, Schoharie, Montgomery, Fulton, Saratoga and Rensselaer counties, and to extend from a little east of Troy westward to Fort Hunter, north nearly to Saratoga and south to Esperance. The presence of the pest on the Mohawk flats made the problem more serious because there was constant danger of high water with the accompanying drifting of corn stalks, some presumably containing living caterpillars, down the river.

The situation was carefully studied in early February and after a series of conferences with state and federal authorities, it was decided to make an attempt to clean up the infestation and prevent the further spread of the pest. The entomologists of the State were unanimous in adopting a progressive policy and as an outcome of their representations the Legislature passed an emergency act appropriating $75,000 to the State Department of Farms and Markets to be used for corn borer control. Although the time for doing effective work was very limited, and conditions in early spring decidedly unfavorable for effective operations, the undertaking resulted in a very satisfactory clean-up of the known infested territory, which at that time approximated 300 square miles. There was then no good ground for believing there would be but one generation of the insect in New York State and that consequently local injury would be comparatively slight because there is only a small variation in climatic conditions between the infested section about Boston, Mass., where two broods are the rule, and the territory where this insect was found in eastern New York. This peculiar restriction could not be demonstrated until mid-September conditions indicated that the borers had ceased activities for the season.

Another infestation was discovered at North Collins, Erie county, in early September 1919, and as a result of scouting by both federal and state men the infested area in that section has been found to approximate 400 square miles and to include portions of Cattaraugus, Chautauqua and Erie counties.

The situation was of more than usual interest since in early spring it was impossible to get more than a tentative identification because Pyraustid larvae, a group to which the European corn borer belongs, are so similar that at the time no unquestioned recognition characters were known. The situation was further complicated by the fact that a very similar borer occurs rather commonly in smartweed and while this latter is of no economic importance, it occasionally bores in corn stalks and it was therefore necessary to distinguish between this harmless native species and the much more dangerous European introduction, if state money was not to be wasted in cleaning up areas outside the infested territory. The Entomologist addressed himself to the early solution of this problem and after securing series of specimens from different sections of New York State and from other parts of the country, worked out differentiating characters which have been largely sustained by later investigations.

Conditions were such in the spring of 1919 that it was very desirable to ascertain at the earliest possible moment the distribution of the European corn borer in the State, consequently bulletins, posters and circulars were widely distributed. The Entomologist prepared a brief circular letter which was sent very generally to schools of the State, Cornell University Extension Bulletin 31, of which an edition of 40,000 was printed, and the Education Department's Bulletin to the Schools of June 1st, the last illustrated by four admirably executed colored plates. Numerous press notices were also sent out. The Department of Farms and Markets published Circular No. 182 and issued a number of quarantine orders. The result of these publicity and regulatory measures was an extraordinary interest in all manner of corn insects and as an indirect outcome valuable information was secured concerning a number of comparatively unimportant pests, notably the lined corn borer and grass webworms.

The European corn borer is of such general importance and its habits in New York State so different from those in Massachusetts that application was made to the Legislature for a special appropriation for the investigation of the status of this insect and $5000 was appropriated. This money is being used in a careful field study of the pest to ascertain the rapidity of spread, the amount of injury and the possibilities of control or repressive measures. The work has been placed in charge of D. B. Young, who was temporarily detailed from the Entomologist's office. Hall B. Carpenter of Somerville, Mass., was also engaged as a special assistant for this work. Data in regard to a large number of fields have already been secured and much material collected which will be duly classified at the close of the active season. Results so far obtained clearly indicate a considerable difference in habits in New York State as compared with the infested areas of Massachusetts. These variations are of much practical importance because of their bearing upon quarantine restrictions or other methods designed to prevent further spread. A detailed report upon this work can not be completed for some months.

Early in July 1919, the Entomologist was appointed collaborator of the Bureau of Entomology, United States Department of Agriculture, and specifically authorized to investigate corn borer control in the states of New York and Massachusetts. He was also appointed chairman of a subcommittee on the European corn borer, subsequently changed to a subcommittee on insect control, of the committee on policy of the American Association of Economic Entomologists and a member of a special committee appointed at the Albany-Boston conference on the European corn borer. He has in these various activities been able to exercise a marked influence upon both state and national phases of the situation. He has felt compelled to do this because the insect is one of national importance and measures adopted in one commonwealth must be contingent to a greater or less extent on those enforced in other states or pressed to a successful conclusion by the representatives of the federal Bureau of Entomology. A detailed account of the investigations and activities in relation to this recently introduced pest may be found in the Entomologist's report.

Other corn insects. The great interest in the European corn borer caused most careful and repeated examinations of corn throughout the State and one outcome was the finding and reporting of a number of injurious species. The lined corn borer, hitherto supposed to be rare in New York State, was found to be rather widely distributed and frequently injuring a considerable proportion of the corn on recently turned sod.

The well-known stalk borer, a generally recognized pest in a variety of thick-stemmed plants, caused numerous complaints, though in most cases the injury was by the corn ear worm. This last was in not a few cases thought to be the European corn borer.

Several less-known corn insects were also brought to the attention of the Entomologist.

The material received during the past season has made possible a more accurate appraisal of the economic status of these different forms and in order to facilitate their recognition a popular key giving the more conspicuous characters was prepared and generally distributed as a special folder. Additional details regarding the work of the different species may be found in the Entomologist's report.

Small grain pests. Studies of the wheat midge, Thecodiplosis mosellana Gehin., begun in 1919, were continued the past season and much additional information secured concerning the economic status of the pest. It was found to be generally present in the rye fields of the eastern part of the State and in wheat fields in the western area. It was particularly abundant in portions of Genesee, Monroe, Niagara and Wayne counties, the indicated reduction ranging from 17 to 27 per cent with very little crop injury from wheat scab or loose smut. The data show close correlation between the abundance of maggots and the number of shrunken or blasted grains of wheat and rye. The evidence at hand indicates a presumably much greater loss from wheat midge infestation than has hitherto been suspected. A detailed discussion of the data is given in the Entomologist's report. The collation of similar data for 1920 is in progress.

The Hessian fly, Phytophaga destructor Say, is one of the most destructive and best known wheat pests. Through the courtesy of Prof. C. R. Crosby of Cornell University and W. R. McConnell of the United States Bureau of Entomology, the Entomologist has been able to include in his report summarized data concerning the abundance of this insect in the State for the years 1917 to 1919 inclusive. It will be seen by reference to the discussion in the body of the report that there has been an increase in the average infestation from 2.6 per cent in 1918 to 7.44 per cent in 1919, the most marked increases occurring in Genesee, Monroe and Wayne counties. These data are of value since they indicate tendencies in different parts of the State and can be used advantageously in designating areas where stricter adherence to precautionary measures is advisable.

Wheat joint worms, Isosoma tritici Fitch and I. vaginicolum Doane, occur throughout the State and as in the case of the Hessian fly, data have been included concerning the abundance of these two insects for the years 1918 and 1919. Reference to the summary in the report of the Entomologist shows a decrease the past season in the abundance of both joint worms, this being particularly marked in Genesee and Schuyler counties with a tendency in the opposite direction in the case of Ontario and Orleans counties.

Observations upon the army worm, Heliophila unipuncta Haw., show that the partly grown caterpillars survived the very severe winter of 1918-19 in Saratoga county, they being repeatedly found in partly rotted corn stalks, and in smaller numbers in the spring of 1920. These are new records for this section of the county and have an important bearing upon army worm outbreaks.

A distinctly unusual feature was the submission of leather jackets or maggots of a crane fly, Pedecia albivitta Walk., accompanied by the statement that they occurred in large numbers in Schuyler county in an oat field and were presumably causing some injury.

Other field crops. The ordinary crop pests attracted comparatively little attention, though in early spring there was considerable complaint of an unusual abundance of asparagus beetles, Crioceris asparagi Linn. These insects were specially troublesome upon commercial beds, not only because of their feeding upon the shoots, but on account of the numerous black eggs which necessitated very careful washing before the asparagus was taken to market.

There was a distinctly unusual outbreak of the green clover worm, Plathupena scabra Fab., upon beans, the greenish white-striped caterpillars feeding generally upon the leaves of both common and lima beans and causing serious and somewhat general injury in various parts of the State.

Codling moth. Field studies of the codling moth have been continued in cooperation with the bureau of horticulture of the State Department of Farms and Markets. Special attention was given to securing exact records of evening temperatures as well as the maxima and minima. The accuracy of this work was materially increased by the cooperation of the United States Weather Bureau in loaning thermographs and supervising the setting up of the instruments. The intimate relations existing between evening temperatures and codling moth oviposition are graphically represented in a chart prepared by L. F. Strickland, who was also responsible for the observations upon egg deposition in various orchards. The demonstration of this relationship is a material step in solving the vexatious problem of codling moth control in the western part of the State.

The series of experiments to determine the relative efficiency of the several sprays for control of the codling moth in the western part of the State have been continued. The most marked results, as were to be expected, were obtained from the first or calyx application and while the reduction in wormy apples was decidedly less in the case of the second and third treatments, there was no question but that these additional sprays are amply justified by other considerations.

Tests of the value of nicotine in the spray applied about three weeks after blooming, indicate little benefit in the destruction of adult codling moths or recently deposited eggs and so far as this insect is concerned, the inclusion of this costly insecticide in the second application can not be advised though it is undoubtedly very beneficial when aphids are numerous. The data in relation to this insect secured the past season are discussed in some detail in the body of the report.

Shade tree insects. The past season was marked by the discovery of another pest in the United States upon which has been tentatively bestowed the common name of elm ribbed cocoon-maker. It is with very little question the European Bucculatrix ulmella Zell. It has been reported as seriously injuring European elms in the Rochester parks.

A recently introduced willow leaf beetle, Plagiodera versicolora Laich., was brought to notice the past season on account of the serious injury to weeping willow foliage in New York City. It is also known as a pest of poplar and may possibly be of some service in checking the indiscriminate planting of this somewhat undesirable shade tree.

The elm leaf beetle, Galerucella luteola Mull., was somewhat injurious here and there in the State, particularly outside of areas where it was very destructive 10 to 15 years earlier. This is probably due in part to better control in localities where the insect has caused the most damage and partly to the somewhat unfavorable climatic conditions of recent years.

The bronze birch borer, Agrilus anxius Gory, continues its nefarious work and here and there throughout the State many magnificent birches are succumbing to the work of this borer. It is only a question of time before all the cut-leaved birches will succumb unless they are systematically protected.

A compilation of the office records of the last twenty years indicate a probable biennial life cycle for the large, strikingly colored Say's blister beetle, Pomphopoea sayi Lec. This insect is numerous approximately every other year when it attracts attention on account of its feeding in swarms upon the blossoms of various trees, particularly honey locust.

Forest insects. The destructive work in recent years of the hickory bark beetle, Eccoptogaster quadrispinosa Say, has resulted in bringing to attention a number of insects of secondary importance. Notes upon these latter have been compiled and are placed on record in a summarized form in the Entomologist's report.

There was an outbreak of the antlered maple caterpillar, Heterocampa guttivitta Walk., in Chautauqua county, accompanied by defoliation of sugar bush in areas where the insects were most abundant.

The interesting maple leaf cutter, Paraclemensia acorifoliella Clem., again attracted notice on account of its unusual abundance in the vicinity of Lake George.

Lectures. The Entomologist has delivered a number of lectures or participated in discussions on insects, mostly economic species, before various agricultural and horticultural gatherings, some of these being in cooperation with farmers institutes or county farm bureau agents; a considerable proportion, owing to the conditions prevailing during the past year, have related to the European corn borer and its control. Some of the more important were before a subcommittee of the United States Senate at Washington, a special meeting of the Council of Farms and Markets at Ithaca, a special conference of state commissioners of agriculture and official entomologists at Albany, the annual meetings of state commissioners of agriculture at Chicago and the American Association of Economic Entomologists at St Louis.

Gall midges. The 33d report of this office, issued during the period covered by this report, contains part 6 of the study of gall midges, a portion devoted to many very interesting and highly complex members of the tribe Itonididinariae, one of the common representatives being the pear midge. The Key to the Sub-families, Tribes and Genera of the Itonididae or Gall Midges of the World, which appeared in the Philippine Journal of Science during the present year, is the most comprehensive paper of this character which has yet appeared.

Gall insects. The "Key to American Insect Galls" was published during the past year. It is the only comprehensive tabulation of these interesting deformities in America and since it deals primarily with the more obvious swellings or plant malformations rather than with the minute and highly complex gall makers themselves, it will greatly facilitate the study of the interrelations between plants and insects. Owing to the great demand for this bulletin, the edition was rapidly exhausted.

Publications. A number of brief popular accounts relating to the more important insect pests have been prepared as heretofore and widely circulated through the county farm bureaus, local papers and the schools.

The Report for 1917 did not appear until the current year and it and the Key to American Insect Galls, mentioned above, are the two Museum bulletins on entomology which were issued during the year. The publications relating to the European corn borer and to gall midges have been mentioned above.

Collections. Very desirable additions to the state entomological collections have been made during the year, some of the best material being reared in connection with studies of insect outbreaks or as a result of requests for information concerning previously unknown forms. Special attention has been paid to the acquisition and preservation of immature stages, since these are very difficult to secure. This is particularly true of a number of borers similar to the European corn borer found in the stems of various plants. The special work upon the European corn borer is resulting in numerous additions to the state collections.

Henry Dietrich, now of Berkeley, Cal., most generously donated to the Museum 551 specimens of Coleoptera, representing 160 species, 55 of these being new to the state collections.

D. B. Young, assistant entomologist, donated from his personal collections of earlier years, a large series of Coleoptera, consisting of 648 specimens belonging to 369 species previously unrepresented in the state collections. This large addition to the collections has necessitated the rearranging of most of the Coleoptera and in addition it involved the study and identification of numerous obscure species. This work has been prosecuted in addition to numerous identifications for correspondents and other routine duties.

Miss Hartman's time has been very fully occupied in addition to the usual duties of the assistant, by the many translations of technical literature needed in systematic work, the making of numerous excellent microscopic preparations of small insects and the arrangement and care of the pressed specimens of insect work and the extensive accumulations of alcoholic material.

The many additional calls upon the staff incident to the work upon the European corn borer has greatly restricted the amount of time which could be given to the identification and arrangement of collections, though some progress has been made along these lines.

The special work upon European corn borer authorized by the last Legislature necessitated the temporary transfer of Mr Young to take charge of the work and the appointment of W. H. Hoffman to fill the temporary vacancy. Hall B. Carpenter has been appointed special assistant in corn borer work.

It is impossible, as pointed out in the previous report, to build up the state collections in a satisfactory manner without more funds and assistance, since work of this character is very exacting and time-consuming.

Horticultural inspection. The nursery inspection work of the bureau of plant industry, State Department of Farms and Markets, has resulted as in former years in a number of specimens representing various stages of insect development, some in very poor condition, being submitted to this office for identification.

The need of accurately identifying borers in weeds and corn found in connection with European corn borer operations of last summer has resulted in the Entomologist giving much time to the study of boring caterpillars for the purpose of distinguishing between the destructive and comparatively innocuous forms. This was very important since the boundaries of the infested territory were necessarily determined by the identifications of all such material.

General. The work of the office has been materially aided as in past years by the identification of a number of species through the courtesy of Dr L. O. Howard, chief of the Bureau of Entomology, United States Department of Agriculture, and his associates. There has been very effective and close cooperation with the State Department of Farms and Markets, particularly the bureau of plant industry, the county farm bureau, the State Experiment Station and various public welfare organizations. A number of correspondents have donated material and rendered valuable service by transmitting local data respecting various insects and assisting in other ways. It is a pleasure to record that there has been, as in the past, a most helpful cooperation on the part of all interested in the work of the office.

ZOOLOGY

The attention of the Zoologist, in the line of investigation, has continued to be directed to the study of the extensive Araneid fauna of the State. Supplementing the general account of the spiders of New York but preliminary to it, a revision of the family Pisauridae has been undertaken and is nearing completion.

Localities selected for field work have included regions of diverse topography in Orange, Ulster and Dutchess counties, and collections of considerable extent have been brought together. Concerning these it is proposed to prepare a separate report.

The report on the molluscan fauna of the State which has received the particular attention of Dr H. A. Pilsbry of the Philadelphia Academy, is now ready for the printer. Doctor Pilsbry's account is monographic in extent and illustrated with many beautiful plates executed in color and in black and white by Helen Winchester.

Dr Roy Miner, of the staff of the American Museum, whose researches on the myriapods of the State were interrupted by war activities, reports considerable progress in the preparation of his memoir.

New groups. The limitations of space in Zoology Hall prohibits the addition of many large habitat groups without a general rearrangement of the existing cases; but small groups of skunks and opossums designed to occupy limited floor space have been installed and other groups are in the course of preparation.

Through the interest and cooperation of the Conservation Commission, the State Museum has received by legislative appropriation, $1500 which will materially increase the collection of fishes from the fresh waters of the State.

The proper care and arrangement of the lesser invertebrates which are usually preserved in alcohol has always been of great concern to the museum curator. With the idea of making such specimens readily accessible and at the same time conserve storage space, a system of suspending small vials on vertical wire screens has been adopted. The supporting screens are filed in specially constructed cases of uniform size but adapted to receive vials of varying dimensions. By this method the handling of individual specimens or groups of specimens is facilitated, and the flexibility of the scheme permits indefinite expansion. Beneath the vertical files, drawer spaces provide room for larger jars of specimens and biological material.

Accessions. Benjamin W. Arnold of Albany, whose extensive collection of birds' eggs was presented to the Museum in 1917, has added an important series of specimens from the Falkland islands. The Henry A. Slack collection of birds' nests and eggs from the vicinity of Albany has recently been acquired through the courtesy of Miss E. Cary. The Museum has also purchased the skull of the extinct great auk to supplement the Shufeldt collection of avian skeletons already in its possession.

As an example of the persistence of certain large mammals in occupying, or perhaps reoccupying, well-settled territory, may be cited the capture of a Canada lynx in March 1920 by Isaiah Kilmer at Jackson's Corners, N. Y. The skull has been added to the collections.

Fragments of the remains of a fossil elephant (mammoth) consisting of skin, muscular tissue, adipocere and hair of varying lengths and texture from Alaska, were the gift of Langdon Gibson of Schenectady. Considerable interest is attached to these specimens because of their identity with the remains of the mammoth found within the limits of New York and because of their extraordinary preservation.

ARCHEOLOGY AND ETHNOLOGY

The work of the division of archeology and ethnology as has been explained in previous reports, covers several fields of activity and includes both field and office research. Beyond this, the nature of our subjects, touching human needs of the present day, places us in demand by several regular and some special branches of state service. Archeology and ethnology deal with the records of human activity, customs, material culture and social organization. Our Indian population with which we are especially concerned, still lingers with us and while constituting an interesting memorial of the past, also presents evidence of the virility and vitality of the Iroquois people. To some extent the existence of separate political units within the body politic creates special problems. Our endeavors thus reach from the most remote antiquity of the red race in this State to the newest of Indian babes.

The office routine of the year has consisted of the work of cataloging, making of labels, preparing of specimens for exhibition, study of records and the caring for requests by numerous correspondents. The fiscal year 1919–20 has brought an unusually large correspondence, indicating in no uncertain measure the value of this division of the Museum to the public and to the specialist.

Our catalog of archeological specimens is nearly complete and includes a serial catalog of all specimens acquired since 1911 and a cross check catalog by subjects. The subject catalog is of special value in determining the relative number of each specimen or class of specimens. The patient work of Howard Lansing, who died two years ago from an injury sustained while in the performance of his duties, has been continued by Harry C. Wardell, the preparator of the Museum.

The collections installed in the various cases have been cared for and certain special exhibits installed. These vary from time to time, as opportunity affords, in order to create public interest. During the winter and spring months the newspapers of Albany, especially the Times-Union, through the interest of Hon. Martin H. Glynn, have published extended accounts of these exhibits. This publicity swelled the crowds of visitors, especially those who came during the period of the Sunday openings. The large numbers of visitors and the appreciation manifested have served to stimulate up-to-date exhibitions and special displays.

The most recent large collection installed is that made by Alvin H. Dewey, Esq., of Rochester. This collection, described in the report of 1918–19, has been placed in the west room of Ethnology Hall. Special cases were made for it and both because of the class of material and the method of exhibition, the collection has attracted much interest and comment.

Public interest. There is a keen public interest in this section of the Museum as evidenced by the numerous visitors that come to our halls. We have sought to cater to the intelligence of the citizen who has not had the advantage of a special technical training in archeology and, at the same time, we have sought to make our exhibits instructive. The large number of letters received asking for information and assistance in various lines with which our subjects concern indicates that we are influencing an increasing field. Many visitors come to the office and give valuable information concerning sites and their location, and others bring or send specimens as donations to our collections.

In this connection it is interesting to note that at least 500 collectors of Indian relics and students of American Indian history and ethnology, within the State of New York, look to this section for information and guidance. Our bulletins are in constant demand and many of them have been entirely exhausted, pointing out the need of larger editions for future publications.

STAFF OF THE DEPARTMENT OF SCIENCE

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

ADMINISTRATION

John M. Clarke, Director
Jacob Van Deloo, Secretary and Director's Clerk
Anna M. Tolhurst, Stenographer

GEOLOGY AND PALEONTOLOGY

John M. Clarke, State Geologist and Paleontologist
David H. Newland, Assistant State Geologist, Curator of Geology
Rudolf Ruedemann, Assistant State Paleontologist, Curator of Paleontology
William L. Bryant, Honorary Custodian of Fossil Fishes
C. A. Hartnagel, Assistant in Geology, Curator of Stratigraphy
Winifred Goldring, Assistant in Paleontology
Charles K. Cabeen, Mineralogist
Esther K. Bender, Draftsman
Noah T. Clarke, Technical Assistant
H. C. Wardell, Preparator
Edith A. Lipschutz, Stenographer
Charles P. Heidenrich, General Mechanic
Stephen D. McEntee, Clerk
John L. Casey, Custodian of Museum Collections
William Rausch, Cabinet Maker
Jerry Hayes, Laborer
Edward Noxon, Laborer

Temporary Experts

Areal Geology

Prof. H. P. Cushing, Adelbert College
Prof. W. J. Miller, Smith College
Prof. G. H. Hudson, Plattsburg State Normal School
Prof. W. O. Crosby, Massachusetts Institute of Technology
Prof. George H. Chadwick, University of Rochester
Prof. Charles P. Berkey, Columbia University
Prof. A. F. Buddington, Geophysical Laboratory, Washington
Marion Rice, Columbia University

Economic Geology

Harold L. Alling, Columbia University
R. J. Colony, Columbia University

Geographic Geology

Prof. Herman L. Fairchild, University of Rochester
James H. Stoller, Union College
John H. Cook, Albany

Paleontology

Dr Rufus M. Bagg, Lawrence College
Florrie Holzwasser, Columbia University
Vincent L. Ayers, School of Mines, State College, Pa.
Herbert P. Woodward, University of Rochester
Joseph Bylancik, Albany

BOTANY

Homer D. House, State Botanist

Temporary Expert

Helen La Force, Schenectady

ENTOMOLOGY

Ephraim P. Felt, State Entomologist
D. B. Young, Assistant State Entomologist
Fanny T. Hartman, Assistant to Entomologist
Helen L. Ryan, Stenographer
Matthew J. McGarry, Page

Temporary Experts

Hall C. Carpenter, Massachusetts Agricultural College
William A. Hoffman, Cornell University

ZOOLOGY

Sherman C. Bishop, Zoologist
Benjamin Walworth Arnold, Honorary Curator of Ornithology
Arthur Paladin, Taxidermist

Temporary Experts

Dr H. A. Pilsbry, Philadelphia
Roy W. Miner, New York

ARCHEOLOGY

Arthur C. Parker, Archeologist

Temporary Experts

Everett R. Burmaster, Irving
William B. Moore, Victor
David Cook, Albany
George Stevens, Albany

ACCESSIONS TO THE COLLECTIONS

GEOLOGY

Donation

Luther, D. D., Naples

Slabs showing mud-flows and beach markings from Naples, N. Y.. 6

Finley, Dr John H., Albany

Photograph of moon, at last quarter, taken September 15, 1917, at Mount Wilson Observatory

Direct photograph of sun taken August 12, 1917, at Mount Wilson Observatory, showing distribution of sun spots.

Spectroheliogram of the sun showing its greatly disturbed surface. Taken at Mount Wilson Observatory August 12, 1917

Gould, Rev. E. W., Bristol, Vt.

Slab of Canajoharie shale showing glacial scratches from shore of Lake Champlain at Panton, Vt...................... 1

Collection

Newland, D. H. & Alling, H. L.

Rock salt and brines from western New York.................. 25

Newland, D. H., Albany

Iron ores of southeastern New York, magnetites, limonites and carbonates 50

Feldspar from Gailor quarry, Saratoga Springs.................. 3

White quartz, Gailor quarry, Saratoga Springs.................. 3

Strontianite from Brayman shale, Schoharie, N. Y............... 7

Pyrite from Brayman shale, Schoharie, N. Y.................... 10

Colony, R. J., Columbia University

Quartz and quartzites from various New York localities........ 25

Alling, H. L., Rochester

Graphite from the Adirondacks................................ 25

Hartnagel, C. A., Albany

Dark gray oolite ore with the spherules of chamosite. From thin band 1 foot below main oolitic iron ore at Clinton, N. Y...... 3

PALEONTOLOGY

Donation

Bryant, William L., Honorary Curator of Fishes, Buffalo

From Conodont bed (Genesee shale) eighteen-mile creek, Erie county:

Specimen with teeth of Dittodus priscus Eastman............... 1

Ptyctodus compressus Eastman................................ 1

Dittodus minimus Huss & Bryant............................... 1

Dinichthys magnificus H. & B. (Fragment of suborbital plate).. 1

Arthrodire or Stenognathus (plate)........................... 1

Dinichthys newberryi Clark (marginal plate).................. 1

Bryant, William L.— *continued*

Machaeracanthus peracutus Newberry. Fragment of spine......	1
Dinomylostoma buffaloensis H. & B. Functional portion of mandible.	1
Ptyctodus calceolus Newberry. Imperfect dental plates..........	2
Ptyctodus howlandi H. & B. Fragment of upper and lower dental plate.	4
Ptyctodus howlandi H & B. dental plates........	3
Palaemoylus sp. Fragment dental plate........	1
Aspidichthys notabilis Whiteaves. Fragment of plate........	1
From Onondaga limestone, Buffalo, N. Y.:	
Demodes bennetti H. & B. Fragments of dental plate........	4
From Rhinestreet shale, eighteen-mile creek, Erie county:	
Rhadinichthys antiquus H. U. Williams........	1
Van Epps, Percy M., Hoffmans, Schenectady co.:	
Disc-shaped concretions from Canajoharie shale 1¼ miles south of Glenville, Schenectady co........	18
Mathes, K. B., Batavia	
Elaeocrinus lucina (Hall), Stafford limestone, Stafford, N. Y...	1
Armstrong, E. J., Erie, Pa.	
Fossil sponges from the Chemung sandstone near Erie, Pa......	4
2 slabs of fossil crinoids........	2
Gyrocers stebos Beecher. (cast) Upper Chemung. Conneautville, Pa........	1
Large slab with specimens of Ceratodictya oryx Clarke. Lower Chemung, 9 miles south of Erie, Pa........	1
Beach markings and worm burrows? Lower Chemung, near Erie, Pa.	5
Simmons, Alfred, Saugerties	
Specimen of Ancyrocrinus, Oriskany limestone, Glenerie........	1
Robinson, W. J., Poughkeepsie	
Normanskill shale, St Andrews Novitiate. Two miles north of Poughkeepsie.	50
Bowman, Charles S., Hornell	
Manticoceras pattersoni, Chemung beds, Hornell, N. Y..........	1
Burling, L. D., Ottawa	
Ordovician (top of Deepkill) graptolite shale from Alaska-Yukon boundary.	10
Caryocaris sp. 5 specimens. Graptolites 2 specimens........ Deepkill shale at Alaska-Yukon boundary	7
Pohl, Erwin, Albany	
Rysedorph conglomerate fossils from Rysedorph hill, Rensselaer county.	225
Gould, Rev. E. W., Bristol, Vt.	
Fossils from Trenton shale, Panton, Vt........	70
Canajoharie shale, lake shore, Panton, Vt........	60

Cole, Rev. Thomas, Saugerties
- Oriskany (Glenerie) Glenerie, Ulster county 509
- Onondaga. Split Rock, Onondaga county 2
- Tully. Borodino, Onondaga county 4
- Hamilton. Skaneateles lake 5
- Hamilton. Mount Marion, N. Y. 13
- Schoharie Grit. Ulster co. (?) Loose Boulder (?) 41
- Carboniferous. Mazon Creek, Ill 8

Powers, Sidney W., Tulsa, Okla.
- Graptolites from Carter county, Okla. .... 48 slabs
- Fossils from Ordovician limestone, Carter, Okla .... 40 slabs

Jones, Leslie W., Amsterdam
- One trilobite and three cephalopods, from Amsterdam limestone, near Amsterdam, N. Y. 4
- Fossils from Amsterdam limestone, Amsterdam, N. Y. 9

Reinhard, E., Buffalo
- Fossils from Ludlowville shale, Athol Springs, N. Y. 6
- Crinoid from Niagaran., Niagara Falls, N. Y. 1

Ginn Bros., Mendon
- Slab of white Potsdam sandstone with trails of Climachtichnites, probably a new species. From the glacial drift on the farm of Ginn Bros., at Mendon Ponds, Monroe county

Chadwick, G. H., Rochester
- Mesopalaeaster sp. Four specimens on one slab. Chemung beds, near Rosses, Livingston co. collected by W. C. Bower 5
- Hallaster sp. part of arm. Locality and collector same as preceding.

Hartley, Robert M., Amsterdam
- Cryptolithus tesselatus Green. Five slabs with specimens 5
  Amsterdam limestone in drift.

Clark, Burton W., Syracuse
- Trenton and Utica fossils from Utica quadrangle 500

Exchange

Reinhard, E., Buffalo
- Fishes from Onondaga limestone vicinity of Buffalo, N. Y. 60
- Rhinestreet shale. Eighteen-mile creek, Erie co., N. Y. 8

Hibbard, Ray R., Buffalo
- Slides of Ordovician bryozoans 35
- Bryozoans from Ordovician of Ohio basin 13
- Mounted conodonts from Conodont limestone of Genesee shale, Eighteen-mile creek, Erie co., N. Y. 7

Ward's Natural Science Establishment, Rochester
- British graptolites 19

Purchase

Ward's Natural Science Establishment, Rochester	
Homalonotus delphinocephalus Green, Rochester shale, Lockport, N. Y.	3
Griffithides scitula Meek and Worthen, Pottsvillian, Brazil formation, Perryville, Indiana	1
Proetus missouriensis Shumard, Knobstone group. Clark co., Indiana.	2
Bumastus ioxus (Hall) Rochester shale, Lockport, N. Y	2
Lyriocrinus dactylus (Hall) Rochester shale, Lockport, N. Y.	2
Life size model of the fossil horse (Eohippus)	1
Gillard, John, Stafford	
Fossils from Stafford limestone, Marcellus shale, Onondaga limestone and Hamilton shale	1750
Reinhard, E., Buffalo	
Pentremites, Loudlowville shale	2
Trilobites, Onondaga limestone, Williamsville, N. Y	5
Corals, Onondaga limestone, Williamsville, N. Y	2
Bertie Waterlime fossils, Williamsville, N. Y	5
Telson of Crustacean, Rochester shale, Lockport, N. Y	1
Macrostylocrinus ornatus, Rochester shale, Niagara Falls	1
Caryocrinus sp. Rochester shale, Niagara Falls	1
Pentremites, Hamilton shale, Athol Springs, N. Y	5
Megistocrinus depressus, Hamilton shale, Alden, N. Y	1
Pentremites maia (?) Hall Eighteen-mile creek, Erie co	1
Pentremites maia Hall Eighteen-mile creek, Erie co	1
Pentremites whitii Hall from Hamilton shale, Athol, Erie co	1
Gidley, J. W., Washington, D. C.	
Six models of the fossil horse (1/5 nat. size) illustrating its evolution	6

Collection

Ruedemann, R. & Hartnagel, C. A.	
Vernon shale from Barge canal excavation at Pittsford, N. Y. Material from under West Shore Railroad bridge	550
Hartnagel, C. A.	
Oolitic iron ore fossils from Clinton, N. Y. All specimens show either the oolitic grains or were obtained from larger blocks which had ore attached. These specimens are from the top of the ore.	80
Fossils associated with blocky shale at base of oolitic iron-ore. Many specimens show the ore, usually separated from shale by a thin layer of pyrite. The specimens are all from a layer about six inches thick directly below the ore. Borst and Franklin Mines, Clinton, N. Y	50

Hartnagel, C. A., Wardell, H. C. & Pohl, E. R.

Clinton shale one-third of a mile due south of Verona Station. In brook below dam.. 20

Clinton shale 1 mile southwest of Verona Station. In small brook back of house of J. B. Weed, about 15 feet below the fossil ore (upper).. 150

Hartnagel, C. A.

Clinton green shale. Red Creek, Wayne co. Creek bank at highway just north of railroad sta. These shales are above the heavy graptolite layers.. 27

Clinton shale, purple, including "pearly" limestone bands. From below upper Clinton Pentamerus limestone. Mudge creek, town of Wolcott, Wayne co.. 25

Clinton green shale and limestone bands at site of old Wolcott furnace 1 mile north of village. These beds are above heavy graptolite shales.. 6

Clinton upper Pentamerus limestone and from shale between the beds of limestone at Mudge creek near Wolcott, N. Y.......... 15

Clinton. Irondequoit shale and limestone in bed of Second creek north of Alton, N. Y. This locality shows coral reefs and the shale between the limestone layers is very fossiliferous....... 37

Clinton shale. From purple beds and "pearly" bands below upper Pentamerus limestone on Second creek near Sodus bay.. 25

Clinton, Limestone bands in green shale above dark graptolite layers. Second creek, Wayne co.............................. 12

Clinton upper Pentamerus limestone. Second creek, Wayne co.. 10

Upper Clinton Pentamerus limestone at Mudge creek, Wayne co. (from quarried stone used around boiler).................... 25

Clinton. Irondequoit limestone. From exposure in first small creek east of Wolcott creek, Wayne co......................... 10

Lockport shale. 10 feet below Vernon red shale. Chadwicks, N. Y.. 25

Clinton, Donnelly quarry and ore pit now filled. Four miles north of Canastota.. 30

Clinton, dark shale just above the iron ore at Sterling Station, Cayuga co. 40

Clinton. Graptolite layers in Palmers Glen near Rochester, N. Y.. 20

Irondequoit limestone. From reeflike layers, Palmers Glen near Rochester, N. Y.. 10

Clinton, Willowvale glen (Rodgers). The specimens are all within 10 feet of the base of exposure about 300 feet west of highway.. 110

Clinton. Newland's Mill near Hecla Works. In shales approximately 20 feet below oolitic ore.............................. 10

Ruedemann, R.

Ordovician. Canajoharie shale, Fort Ticonderoga on road from railroad station to Ticonderoga.............................. 17

Ordovician (Canajoharie) shale at east shore at Willsboro Point.. 21

Ordovician (Trenton) shale at Stony Point 2 miles south of Rouses Point.. 41

Ruedemann R.—*continued*

Ordovician (Trenton) shale in town of Alburg, Vt., at Windmill Point	5
Ordovician (Trenton) shale in town of Alburg, Vt., at ice-house of Rutland R. R	34
Ordovician (Trenton) shale at Cumberland Head	44

Gould, Rev. E. W. & R. Ruedemann

Ordovician (Canajoharie) shale and Trenton limestone. Lake shore at Panton, Vt., north of Arnolds bay	53

Clarke, John M.

Thylacocrinus gracilis (Hall) Hamilton shales, Bethany, N. Y.	1

MINERALOGY

Donation

Col. William B. Thompson, Cobalt, Canada

1 Silver and bismuth

J. B. Lain, Kennicott, Copper Co., Alaska

1 Chalcopyrite	Latouche, Alaska
1 Malachite	Latouche, Alaska

Purchase

Ward's Natural Science Establishment

3 Opals (precious)	Virgin Valley, Humbolt co., Nevada

Wright, William K., Niantic, Conn.

A geode cavity partly filled with banded chalcedony (onyx) and lined with quartz of peculiar crystal form. From Desolation islands, off west coast of Tierra del Fuego, S. A.

Exchange

Holzman, John, Newark, N. J.

1 Hematite (specular)	Lake Superior, Mich.
2 Molybdenite in hornblende	Tintic District, Utah
3 Cuprite in chrysocolla	Tintic District, Utah
4 Stibnite	Elco, Nevada

Pope, F. J., Yonkers

1 Bornite	Magma Mine, Superior, Ariz.
1 Asbestos	Globe, Ariz.
1 Sphalerite on chert	Miami, Okla.
1 Polished lapis-lazuli	Cordillera de Ovalle, Chili, S. A.
1 Chalcocite	Kennicott Mine, Alaska

Mott, E. C., Yonkers

1 Malachite	Gila co., Ariz.
1 Azurite	Bisbee, Ariz.
1 Cuprite	Gila co., Ariz.
1 Malachite	Bisbee, Ariz.
1 Silver	Ontario, Canada
1 Annabar	Terlingua, Texas
1 Crysocolla	Gila co., Ariz.
1 Amethyst	West Paterson, N. J.

Ward's Natural Science Establishment

1 Tetrahedrite, pyrite and quartz	Bingham Canyon, Utah
1 Hematite (Kidney ore)	Cumberland, England
1 Chalcopyrite	Ugo, Japan
2 Opal in matrix	
2 White opals	
1 Fire opal	
4 Moonstones	
2 Tigereye	
2 Yellow chalcedonys	
3 Lead glass	
2 Quartzes	
2 Zircons	
3 Rhinestones	
2 Almandine garnets	
3 Amethysts	
2 Imitation amethysts	
2 Aquamarines (beryl)	
2 Synthetic sapphire	
1 Sodalite	
2 Lapis-lazuli	
2 Turquois	
2 Turquois in matrix	
2 Enamels (turquois imitation)	
2 Glass doublets (blue)	
2 Emeralds	
1 Brazil emerald (tourmaline)	
1 Ceylon peridot (tourmaline)	
2 Chrysolites (peridot)	
1 Epidote	
1 Bloodstone	
1 Jadeite	
1 Jade	
4 Doublets (green)	
1 Strontianite	Drensteinfurt, Westphalia
1 Franklinite	Franklin, N. J.
1 Sphalerite	Joplin, Mo.
1 Cryolite	Ivigtut, Greenland
1 Large gypsum crystal	Wayne co., Utah
1 Large malachite and azurite	Bisbee, Ariz.

Photograph of a "Relief model of Syracuse and vicinity." Published by the New York State Museum. The two improved state highways that make the phenomena described in the bulletin immediately accessible to motorists are indicated by heavier road lines.

Plate I

ONEIDA LAKE
Frenchman Isl.
ONEIDA RIVER
PHOENIX
OSWEGO RIVER
BALDWINSVILLE
Belgium
Euclid
Cicero
Cicero Center
Cicero Swamp
North Syracuse
Long Branch
Liverpool
ONONDAGA LAKE
Ley Creek
East Syracuse
Butternut Creek

THE TULLY GLACIAL SERIES

BY O. D. VON ENGELN

SCIENTIFIC PAPERS

Introduction

The purpose of this paper is to direct attention to and to describe a series of glacial phenomena that have a remarkable scenic and scientific interest and are also so easily accessible to large population centers in the State, and to tourists and students generally, that it seems strange that their significance has been hitherto almost overlooked.

The region in which these associated glacial phenomena occur is in the Finger Lakes district of the central part of the State and shares in the general scenic attractiveness of that section. Here are found rolling hills sufficiently high to be impressive and yet not so steep as to be an obstacle to motor travel. From many vantage points along the improved roads broad landscapes of field and forest-checkered slopes come into view and bold prospects across and along deep, steep-sided valleys are frequently encountered. In the latter the larger Finger Lakes are ensconced and in smaller hollows numerous lesser bodies of water are cupped. Thus a most varied and pleasing panorama is unfolded to the traveler and, whether he moves swiftly in train or motor car or goes leisurely afoot, he will find that very little of this panorama is monotonous, either in its broader aspects, as when seen from the road, or when studied intimately with a view to the interpretation of its details.

But aside from the general attractiveness of the region, that section of it which extends as a belt to the north and south of the village of Tully has long been a center of considerable interest to New York State students of geologic science. This section should also have an appeal for the very much larger number of residents of the State to whom it is easily accessible and who are of the group that derives pleasure in visiting scenic phenomena that are out of the ordinary.

Tully is located about halfway between the cities of Syracuse and Cortland, which are about 30 miles apart on a north-south line. An excellent state highway extends directly along this line and another of these highways intersects the first at Tully so that all the features herein described can be easily reached.

The Tully "Glacial Series"

The topographic situation of the features to be described is well shown in the photograph (plate 1) of a relief model of "Syracuse and Vicinity" published by the State Museum. While the model indicates very well the bolder features of the topography and the scenic diversity of the region, it was not made with a view to bringing into relief the particular glacial details of the landscape, hence does not show the features discussed in the following pages in so striking a fashion as these themselves present when seen in the field.

The Tully area exhibits compactly what has been termed by Penck and Brückner, in their work *"Die Alpen im Eiszeitalter,"* a "glacial series." By this phrase it is meant to characterize the typical succession and association in which the various evidences of the occupation of an area by glacial ice will be encountered after the ice has melted away. Figure 1, adapted from Penck, shows the several

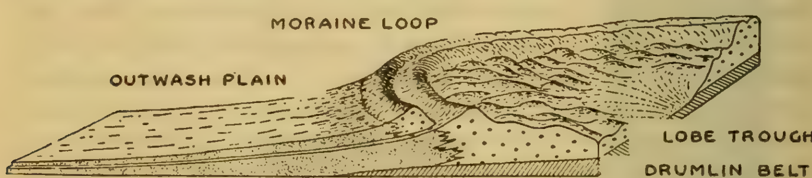


FIGURE 1. Diagram of the typical glacial series of the Alpine Glaciers. (After Penck)

members of such a series in their areal relationships and gives some idea also of the forms of which the series is comprised. Figure 2 is a reproduction of Penck's mapping of the actual occurrences of such a series on the Swiss plateau. In correlating the New York region, centering at Tully, with the Alpine area which these figures illustrate, Lakes Ontario and Onondaga would correspond with the Bodensee, the drumlin country and channels about Syracuse (drumlins are shown on the photograph of the relief model, plate 1) would match the drumlin and channel occurrences to the north and west of the Bodensee, the upper courses of the several rivers, Rhine, Danube etc. would be (less nearly) equivalent to the Finger Lakes valleys of New York and the Onondaga valley. The "Young End moraine" correlates with the morainic deposits at the heads of the Finger Lakes valleys, and, specifically again, to the barrier across the Onondaga valley west of Tully village, and finally, the small patches of "white-dot-on-black" symbol "Younger Deckenschotter" (outwash) outside the Young End moraine correspond to the much more

Figure 2 Map of the Rhine glacier deposits. (After Penck.)

extensive accumulations of such sediments on the south slopes of the continuations of the Finger Lakes valleys and, specifically once more, over the wide valley-flat south and west of Tully village.

While the correspondence in occurrence in both regions is sufficiently exact to be indicative of the typicalness of the succession, and in so far is suggestive, the two areas nevertheless differ in a number of respects. The Tully area has features that are lacking in the Alpine map and others that are much more characteristically developed than in the European region. The Tully area would therefore warrant separate discussion if only because of these differences. In pointing out such correspondence as exists there has been anticipated a general statement of the origin of these glacial series and, as such an explanation will be essential to a competent appreciation of the individual phenomena to be found in the Tully section, it follows next.

Development of the Tully Glacial Series

When the first advance of the glacial ice reached the Tully region it encountered a considerable topographic barrier, the northern escarpment of the Appalachian plateau, here formed by the outcrops, in an east and west belt, of the resistant Onondaga and Tully limestone formations. These are both massive rock layers in contrast with the soft shales which lie under each of them. Because of the greater resistance such massiveness gave these limestone layers when under attack by the agencies of weathering, frost and solution, they had broken down much more slowly than the shale materials; hence a cliff topography developed at the outcropping edges of the limestone layers. Such is the history of weathering escarpments generally and the Onondaga-Tully escarpment is no exception to this. Once these more resistant layers had been broken down over a given area, the soft shales beneath them crumbled rapidly and their fragments were borne away by the streams. Immediately to the north of the line where the limestones still exist a broad lowland was therefore formed, the Lake Plains; while to the south of this line the country, still capped and protected by these more durable rocks and also by the resistant Portage sandstones, kept a higher level and made the beginning of the upland areas which in their larger aspect are called the Appalachian plateau. The difference in elevation so caused is of considerable magnitude and well defined, and it may therefore be well termed a barrier to an ice mass moving down from the north. Thus the actual rise from Syracuse to Tully, going up over the edge of the limestone outcrops and to the Portage sandstone summits is approximately 1600 feet in a distance of some 12 miles along a north-south line. The difference in elevation between the Lake Plains and the Appalachian plateau uplands is well shown in the photograph of the relief model (plate 1).

It must not be understood, however, that this escarpment presented in preglacial times a solid unbroken cliff. Drainage collecting on the upper levels and flowing down over the edge of the steep north-fronting outcrops in streams of considerable volume, cut notches in the edge of the cliff, which in time were deepened and widened into considerable valleys; and such valleys then were also extended back, or southward, by headwater erosion for significant distances into the upland country. Accordingly the escarpment in preglacial times probably presented a number of broad salients projecting northward separated one from the other by narrower valleys, widest at the north; and pinching out into the upland in the form of the letter V laid flat with its open end toward the north and drawn very tall and narrow. In a general way such has continued to be the topography of the escarpment front in glacial and postglacial time except that the valley feature has been much accentuated in depth, width and length and most extraordinarily modified in extension and form. The occasion for these changes in the valleys is to be found in the action of the ice.

In the movement of the glacial ice it would be manifestly improbable that the thin edge of its front, on encountering so high and steep a barrier as that of the escarpment described above, could be shoved up over such a slope and then across the broader uplands of the Appalachian plateau itself. It is evident, accordingly, that the escarpment slope acted as a dam, holding back the glacial flood until so much ice had been brought forward from the north as to make the ice thickness along the barrier as great as the height of the topographic obstruction. Only then could the glacial flow southward be recommenced in the form of a submerging ice sheet.

Meanwhile the water-cut and weather-widened valleys of the main streams draining to the north and notching the escarpment slope, themselves of considerable dimensions both as to depth and width, must have afforded channels into which the ice could thrust projections of notable length before the general front of the advance had overtopped the plateau level. As the ice became thicker and thicker such projections were elongated more and more and when the ice finally overflowed the upper levels the deepest and presumably most freely moving parts of the mass necessarily continued to follow the path-

Scale 62500

Contour interval 20 feet

Datum is mean sea level

TOPOGRAPHIC MAP OF THE TULLY GLACIAL SERIES AND ADJOINING AREAS.

Parts of the Syracuse, Tully and Cortland Sheets of the U. S. Geological Survey Topographic quadrangles. Marked to show location of the several phenomena of the Glacial Series.

ways opened by the stream channels. Such is the nature of the flow of the Greenland ice now through the gaps in the mountain rim that incloses the interior ice field of that vast island. The erosive activity of glacial ice is dependent for its relative effectiveness, primarily on the comparative thickness of the ice, and hence it follows that these north-south valleys, with their deeper and more rapidly flowing ice currents, were eroded at a much faster rate than was the general surface of the upland. As such differential erosion would tend still further to deepen and straighten the north-south channels, and so in turn facilitate the flow of the ice in them, it also operated progressively to accelerate the rate of the differential erosion along such lines. This combination of circumstances by concentrating the ice flow and hence erosion, ultimately resulted in the carving out of notable troughs in the mass of the plateau rock. At the head of the preglacial, north-sloping stream valleys there must have been a more or less rooflike ridge or divide separating the drainage that followed such valleys to the north from that which went down other valleys on the south slope. The ice tended to file down these ridge-divides, for the wedge form of such divides necessarily contained less mass of rock material than the unconsumed continuous masses on either side. Moreover such divides were right in line with the more rapidly moving currents, hence bore the brunt of the ice-erosion attack. Accordingly the preglacial north-sloping and south-sloping valleys were more or less regularly linked together by having their separating ridge cut away by the ice and thus were developed the characteristic *through valley* channels of the glaciated sections of the Appalachian plateau. The valley now drained by Onondaga creek to the north and by a branch of the Tioughnioga river to the south, with an *in valley* divide of glacial accumulation, at Tully, is a typical example of a trough of such origin, as are also the valleys of Butternut creek to the east, and of Otisco, Skaneateles and Owasco lakes on the west, all clearly illustrated on the photograph of the relief model (plate 1). Note also on this figure how the trend of the axes of the drumlin hills, extending from the northwest to the southeast toward Syracuse, lines up exactly with these through-valley troughs and so indicates that the direction of the general flow of the ice was exactly so oriented as to make these valleys the gateways for the movement farther south.

In the foregoing paragraphs the competence of the ice to erode the masses of solid bedrock over which it passed has been postulated without explanation of how this process acts. It is, however, essential to a clear understanding of the phenomena consequent on such action that the manner of this be stated. As the ice first passed over the country from the north it picked up, and incorporated in its bottom layers, all the loose pebbles, boulders and sand and soil particles that covered the preglacial surface and moved these along southward. Moreover it pried loose projecting blocks of the bedrock material, where such occurred, and added these to its burden. Thus its bottom shortly became a rock-and-earth-studded ice mass, pressed down on the floor of the country over which it moved forward by all the thickness of the overlying ice. Since the ice eventually overtopped the highest of the Adirondack summits it must have ultimately attained a thickness of several thousand feet. After the unattached and projecting rock stuff had been removed, the later advances of thicker ice wedged and plucked loose fragments of the fresh bedrock; thus its bottom was continuously shod with boulders and also with scouring material of a finer sort. Aside then from its mass action as a plucking agent it is apparent that this boulder and sand furnished bottom-ice, pressed down by all the great thickness of the glacial mass above, must have been a grinding and scouring agency of immense effectiveness and hence been competent to carry away great quantities of rock material during the thousands of years that the ice occupied the country.

There was, however, a south limit to the ice advance, and there, as the ice melted, all the debris that had been picked up enroute was necessarily dumped. Some of it was heaped up in ridges along the front of the ice as it melted out; much of the finer material was carried away from the immediate front by the streams created by the ice melting. The heaped-up ridges of rock rubbish dropped by the glacier are termed *moraines;* the material carried forward from the front and distributed by streams is called *outwash.* As the glacial climate moderated and the supply of ice from the north was no longer sufficiently great to maintain the front at the southernmost latitudes reached at its maximum extension, the ice front itself receded, not by any *movement* backward, but simply by melting back faster than it could be supplied by flow forward. The interesting fact in regard to this amelioration of the glacial climate is that it apparently was not continuous, but occurred rather in distinct steps, so that there were successive halts and stands of the ice front east and west across the country. At each of these lines, where an equilibrium was established for a time between supply and melting, the rock rubbish was heaped up in moraines, and outwash deposits were formed, just as at the farthest front of advance; the mass of such accumulations depending on the length of time that the halt continued. Where the equilibrium was established across a region of no great topographic irregularity, as in the central west of the United States, the front of the ice would have a relatively straight outline; but where the front, during a halt in the melting, rested over a region of notable relief, as in any part of the Appalachian plateau, it would be very irregular in outline for, as during the advance, tongues of ice would project far southward along the valley lines. This condition would in fact be much accentuated during the retreat of the ice, as the ice erosion during glacial occupation greatly enlarged these valleys in cross-section and made them straight and continuous over long distances north and south by obliterating the preglacial divides. Accordingly it may be conceived that long narrow lobes of the ice extended southward beyond the main front along such valley lines, while the hill country between had been melted clear of ice. On the summits the ice was thinner and also more stagnant, hence would disappear more rapidly than in the deep troughs with their greater thickness of ice and freer supply.

The point to this somewhat lengthy statement of conditions at the time of a halt of the ice, with reference to the Tully glacial series, is that such an equilibrium occurred just there and, jointly with the erosive action of the ice, was responsible for the phenomena exhibited in this section. About a mile to the west of the village of Tully and about a mile to the north there is encountered a very steep slope in the floor of the southward continuation of the Onondaga valley, a descent of some 300 feet within a mile. This declivity marks the inner side of a huge morainic accumulation made by a lobe of ice that extended up to this point in the valley and rested there for a long time. This declivity is not indicated very sharply on the photograph of the relief model (plate 1), but is a very marked feature on the topographic map of the region, plate 2, on which it is labeled "Tully moraine." It is shown graphically in the photograph (plate 3) taken from a point on the inner side of the moraine itself, just where the deposit joins the valley wall on the west side. The gentler slope to the south is the front of this moraine, and the wide flat plain with the lakes is the outwash accumulation that was formed at the same time.

References to the Tully Glacial Series in the Literature

Having gained now a general acquaintance with the glacial history of the region, it will be interesting to pause, before considering its special phenomena, to note such references to the area as occur in geological literature.

The close areal association of such a variety of glacial phenomena. and their intimate and interesting relationship as members of a connected series, and thus the unusual opportunity afforded in this region of comprehending a variety of glacial phenomena by field study, rarely afforded by so restricted an area, has in some measure been overlooked; but it must not be thought that the striking individual features exhibited here have altogether escaped the attention of geologists. Early in the history of the New York State Geological Survey, when the theory of continental glaciation had but recently been announced and had not yet gained wide acceptance; that is, at a time when geologists generally were much puzzled by such extraordinary accumulations of loose material as the moraines present, Vanuxem[1] writes:

There is another class of deposits, well defined as to position but irregular as to composition, which are worthy of note. They occur in north and south valleys which are on the south of the Mohawk river and the Great level; or in other words, the Helderberg range forms generally the dividing line between their north and south waters. These waters anciently flowed in one same direction, through valleys still more ancient than themselves; but they now separate, and flow over double inclined planes in opposite directions.

The whole of these deposits have a common character, they are in short hills quite high for their base, and are usually in considerable numbers. None were opened and no opportunity offered to ascertain if any defined arrangement of their materials existed or had been made when deposited. They consist of gravel, of stones also of greater size, sand, and earth. . . . In Onondaga valley there are two deposits . . . (the second) is a lesser deposit near the head of the valley (the Tully moraine). . . . The hills appear to have been formed by the waters of creeks when the lake was at a higher level for where such substances are deposited in deep and tranquil waters there is no tendency to diffusion [i. e. irregular, hummocky deposits].

It will be noted that Vanuxem assigned the morainic deposits to the action of rapidly moving stream waters; also that he failed to appreciate that the hillocks which he saw were but the surface excrescences of a much larger mass of material extending solidly between them and below them to the rock floor of the valley. This irregular surface expression of the moraine is very characteristically illustrated in plate 4, a photograph made on the summit of the Tully moraine on its east side just off the improved state highway that parallels the valley.

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[1] Vanuxem, L., Natural History Survey of N. Y. 3d Dis't, 1842, p. 218.

View of the steep inner side of the Tully moraine. Seen from the west end of the moraine itself, near where this joins the valley wall. Looking southeast.

Characteristic hummocky surface of the top of the Tully moraine. Near its east margin, just off the improved state highway parallel to the Onondaga valley. Looking north.

In 1882 Chamberlin[2] notes that his assistant, R. D. Salisbury, "observed a very fine development of the chain (of moraine) in the Tully (*sic.*) valley." On the earlier page cited he states that he considers all the line of morainic hills, of which the Tully occurrence is a part, as the terminal moraine "of a very important advance of the great ice-sheet at a date considerably later than the stage of greatest glaciation, or, in other words, to outline the ice limit of a second glacial epoch." It will be noted that this interpretation is at variance with the one given in the preceding section of the present paper, where it is stated that the Tully moraine (and this statement applies equally to other moraines similarly located at the valley heads in the Finger Lakes region) marks, merely, a prolonged halt in the retreat by wasting due to melting and evaporation, of the last advance of the ice which extended at its maximum stage a considerable distance south of this line. It is possible that Chamberlin's inference is in so far correct that the *Wisconsin Ice,* as the last great advance is termed, had two phases, an earlier and a later forward movement, separated by a considerable time interval, and that the second forward thrust did not extend so far to the south as did the first. In that event the line of valley head moraine in the Finger Lakes region may mark the *near maximum* stand of the ice at the time of the second Wisconsin advance, but the opinion that it was the actual terminal of this ice does not now find general acceptance by glacial geologists.[3] If it were the actual terminus, extensive deposits of older, more weathered glacial material should occur immediately south of the morainic line, and this has not been observed. Moreover, other notable lines of moraine occur to the north, and the changes in the higher levels of the lake waters that preceded the present Great Lakes indicate that the withdrawal of the ice was, as postulated, by steps, and not a steady progressive melting away.

The authors of subsequent papers dealing with the effects of glaciation in this part of New York State, who make reference to the Tully area have been so engrossed in the work of tracing the glacial lake history of the region, following up the original suggestion made by the late G. K. Gilbert, that they give only incidental mention to other features. Thus Fairchild [4] refers to the heavy moraine that

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[2] Chamberlin, T. C., The Terminal Moraine of the Second Glacial Epoch, Third Ann. Rep't, U. S. Geol. Sur., 1883, p. 357 and 302.

[3] See Tarr, R. S., The Physical Geography of N. Y. State, N. Y. 1902, p. 127–28.

[4] Fairchild, H. L., Glacial Waters in the Finger Lakes Region, Bul. Geol. Soc. Amer., 1899, v. 10, p. 57–58.

" extends from the divide at the Tully lakes northward for two miles . . . The moraine is very gravelly and the hills are really kames. . . . The small northern lakes seem to occupy kettles in the moraine filling. The outlet channel may be regarded as beginning below the lower lakes, Crooked lake and Tully (Big) lake, which have an elevation of 1193 and 1189 feet. These are shallow and probably lie in depressions due to ice blocks. The Tioughnioga valley, which heads at this point, will be discussed, with its heavy detrital deposits, at some future time." In another paper [5] the same author states that, " In the Onondaga valley the highest water was the Cardiff lake which had its outlet south through the Tully lakes," but it does not appear that the promise of publication on the features of the Tioughnioga valley has been yet redeemed. The most recent paper relating to the region is New York State Museum Bulletin 171, by T. C. Hopkins, entitled " The Geology of the Syracuse Quadrangle " in which there is a brief discussion of the channels and terraces of the Onondaga valley (p. 41-42) but no specific description of the glacial history of its south end is included. Inasmuch as this south end lies in the Tully quadrangle, its description would, indeed, not have been warranted under the title.

For a detailed record of the basic geology of the Tully quadrangle with a map showing the differentiation of the rock floor on which rest the superficial deposits here discussed, reference is made to Clarke, J. M. and Luther, D. D., New York State Museum Bulletin 82.

The Particular Phenomena of the Tully Glacial Series

Drumlins. The flow of the last advance of the glaciers, and presumably of the earlier advances as well, was turned by the Adirondack uplands from a direct southerly course into the Ontario basin and from thence the ice deployed southeast across the level lowland of the lake plains to the face of the Appalachian plateau escarpment described on preceding pages. The parallel orientation of the drumlin hills so markedly apparent in the photograph of the relief model gives a clear index of the line of motion of the mass, at least in its declining phases, and the fact that the ordering of the drumlins is in exact alignment with the valley channels opening southward into the plateau uplands is indicative that such was also the direction of flow during the major occupation.

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[5] Fairchild, H. L., Pleistocene Features in the Syracuse Region, Amer. Geol., 36: 136, Sept. 1905.

The drumlins are the first item in the glacial series under discussion and may be seen in typical development about the southwest corner of Onondaga lake or in the area that comprises the southeast suburbs of Syracuse. Their nature and probable origin have been described at length in New York State Museum Bulletin 111 by Fairchild, hence will not be considered further here.

Troughs of glacial erosion. Turning again to the photograph of the relief map of the region it will be noted that four major valleys, from east to west, those of Butternut creek, Onondaga creek, Otisco lake and Skaneateles lake, and part of a fifth, Owasco lake, are shown, all of which have a general northwest-southeast trend and represent both the main channels of the ice movement and the work of erosional excavation wrought by the ice itself. On further inspection it will also be evident that the Skaneateles and Otisco valleys, which lie most directly in line with the ice motion, as indicated by the alignment of the drumlins, have been gouged out most deeply and uninterruptedly. In the area to the east, including what are now the Onondaga and Butternut Creek valleys, the drainage from the north face of the escarpment seems to have been only through valleys trending almost directly northward and, hence, at a distinct angle with the ice advance deploying southeastward. As indicated by the orientation of tributary valleys on the uplands, a major part of the drainage of this section was to the south, though, because of possible glacial and interglacial modification of their courses, only inferential reliance may be placed on this evidence. In any event, either because of the adverse trend of the preglacial north-sloping valley gaps with respect to the ice advance, or because these were smaller, there does not seem to have been in this section so effective and deep scouring action as in the valleys to the west. Hence, although the rock floor of the Onondaga valley is deeply buried under accumulations of glacial and stream transported débris, and ice erosion, accordingly must have cut down to considerable depths below the present surface level, ice erosion did not carve out a basin sufficiently deep to survive as a lake, as was the case with the two valleys to the west. Evidence that the ice flowed more freely and persisted longer in the lake valleys than in the Onondaga valley is afforded by conditions at the south ends of the lake valleys and is set forth below.

The Onondaga valley, though not so deeply cut as the lake valleys is, nevertheless, a typical example of a *glacially eroded trough* and, as such, is comparable to the valleys similarly carved in which existing valley glaciers of the Alaskan mountains, of the Alps, of the

Caucasus, New Zealand and Patagonia flow, and which they have formed by their particular erosive activities. There is this difference: the existing valley glaciers flow down their channels and are confined by them, whereas the Onondaga valley and the Finger Lakes valleys to the west of it were scoured out by ice *currents* in the main ice sheet of a continental glacier *flowing more freely up and through them* than over the upland spurs between the valleys.

That such through-flow produces a glacial trough having the same characteristics as those developed by valley glaciers is well demonstrated by the photograph (plate 5) of an ice-eroded valley on a *nunatak,* or projecting peak, of the barrier-mountain rim of Greenland; a valley the bottom of which is at a level above the present lesser development of the ice. The ice at a higher stage passed through this gap in a current from the main sheet, on the side from which the photograph was taken, toward the ocean. If the Onondaga valley and its continuation southward were dug free of all loose deposits its bedrock form would very closely resemble that shown by the Greenland valley. Such ice-eroded valleys have been typified as U-shaped in contrast with the normal V-shape of valleys due to stream-cutting and weather-widening. The comparison to the capital letter U is not altogether exact for it will be noted that the arms of the U in the Greenland valley (and of other glacially eroded troughs) are not vertical, but slope outward as would result if one should pull the U arms slightly wider apart at the top.

It is not to be conceived, as some observers seem to have thought, that these troughs in the Finger Lakes region were carved out by the projecting lobes of the ice in its retreating phase; neither was the cutting done by similar lobes in the advancing phase, nor even by one advance. The major excavation was probably accomplished when the ice attained a maximum thickness and extended solidly over the area in each of the several advances that may have occurred. The advancing lobes presumably scoured the initial paths but the retreating lobes probably did more, through deposit of detritus at their ends, to fill up the depressions than to accentuate them.

In one sense, however, the lobes of the retreating ice were responsible for the preservation of these troughs. By extending southward beyond the main line of the front they tended, for the duration of any marked halt in the withdrawal, to concentrate deposits in great masses at their ends, because all the ice slopes and their drainage from melting and precipitation tended to focus at such points. Hence, when, after a period of equilibrium between supply and wastage marked by a relatively fixed position of the ice front, there came

Plate 5

Glacial erosion trough, Sentinel Nunatak, Bowdoin glacier, west coast of Greenland. Trough scoured out by ice current when interior ice of Greenland was at a higher level. Illustrates typical cross-section of an ice-eroded valley. Photograph by William Libby.

Plate 6

Glacially eroded Onondaga trough, east side. Opposite the village of Tully Valley.

a period of more rapid wasting there would be a more than average rate of withdrawal in the lobate portions; for these projections may be likened to the dial hands of various gauges whose points swing over a wide range of degrees when their centers are only slightly displaced. A slight reduction and melting northward of the great bulk of the main ice mass would bring about a much greater lineal withdrawal of the attenuated, " sensitive " tips of the lobes, hence a more rapid one, and such process would tend to keep the portion of the trough in which the lobe had rested before comparatively free of detritus deposits made directly from the ice.

The Onondaga trough is a secondary and accentuated example of the lobe basin of figure 1. It corresponds most exactly with Lake Thur in figure 2. Minor projections of larger lobes rested in both hollows and their relatively rapid melting preserved the basin effect.

Hanging valleys. Genetically, however, the Onondaga trough is the result of ice erosion and it should be discussed as being of such origin. Its form, as seen from both sides, is well illustrated by plates 6 and 7, the former showing the east side, the latter the west side, both opposite the village of Tully Valley. In plate 6 note the level summit of the upland, comparatively little modified by glacial erosion, and the oversteepened slope of the Onondaga trough extending as a straight-line cut through the area. Plate 7, the west side opposite, shows the steep slope quite as clearly and illustrates another characteristic effect due to the differential action of glacial erosion, namely the creation of *hanging valleys* and the postglacial development of rock gorges on their lips. The cross-section form of the hanging valley and of the top of the postglacial gorge has been outlined in ink on the photograph so that the reader may be able to identify them clearly. The summit that appears in the distance in the center of the hanging valley depression is the hill, 1620 feet high, lying to the west of Maple Grove (Case P. O.) on the topographic map.

The thicker ice currents, moving freely through the valley channels with axes parallel to the general direction of the ice advance, notably deepened, widened and straightened such depressions during the course of the ice invasions, as is well illustrated by the Onondaga valley. Preglacial valleys with courses lying athwart the direction of the ice motion were, on the other hand, modified little if at all by the ice scour. In general with the rest of the upland country they were probably planed down somewhat but there was no concentration of erosive effect along their lines, and they may even have escaped the full erosion of the uplands; for their furrows would tend to obstruct and stagnate the movement of the ice which filled them. Hence it came about that, on the melting of the ice, such east-west cross-valleys were left with their lower ends "hanging" far up on the sides of the much more deeply ice-eroded, north-south valleys to which they are now tributary. In preglacial time these east-west tributaries no doubt came into the main valleys *at grade,* that is, there was no declivity, waterfall or gorge at their junctions with the main valleys, because the preglacial weathering and stream-erosion processes of valley-cutting proceeded concurrently and accordantly in the main and tributary valleys, the smaller stream cutting down a narrow valley as fast as the large stream cut down a broader one. Moreover, as will be noted by the cross-section of the hanging valley in plate 7, this process of stream-valley development had proceeded to a stage of *maturity,* that is, there had been sufficient time for weathering to make the tributary valley wide open by wasting away the rock of its sides.

The present depth of the main valley below the level of the bottom of the mature hanging valley gives, therefore, a measure of the differential, glacial cutting-down of the north-south trough. The visible portion of this amounts to 600 feet in depth and the rock floor of the Onondaga trough is buried under loose drift of an undetermined thickness, probably more than 100 feet. It may therefore be safely reckoned that differential ice erosion lowered the bottom of the north-south Onondaga valley by some 700 feet. Plate 8 is introduced to illustrate the same process of hanging valley creation in a region of existing glaciation, but this example differs from the Onondaga occurrence in that both main and side valleys were subjected to ice erosion, the former by a deep and broad ice stream, the latter by a relatively thin and feeble one, hence the difference in the extent of their erosion and the creation of the hanging valley condition.

Postglacial gorges. After the last withdrawal of the ice the stream drainage of the present period was initiated. Where the tributary streams encountered the glacially developed, precipitous descents due to the oversteepened valley sides of the main trough, waterfalls occurred. As postglacial time passed these waterfalls, located on horizontally bedded stratified rocks of varying resistance changed from an original single straight fall, first to a series of step falls from one durable layer to the next and then, by recession of their cascade crests, after the manner of waterfalls so conditioned, there was cut a rock gorge in the lip of the hanging valley, as illustrated in plate 7. The occurrence of such rock gorges at the lower

Plate 7

Glacially oversteepened Onondaga trough, west side. Opposite village of Tully Valley. Crest line of upland broken by cross-section of the end of a hanging valley (marked by dashed ink-line) and the lip of the hanging valley cut into by a post-glacial rock gorge (top of which is indicated by a solid ink-line).

Plate 8

Hanging valley, Nunatak Fiord, Alaska. Both main and side valleys are glacially eroded, the former, however, much more deeply because of the greater effectiveness of the larger ice stream. Note notching of lip of hanging valley due to post-glacial stream erosion.

ends of the hanging valleys is the distinctive mark of a notable interruption in the stream erosion and weathering development of the side valleys; and the measure of the depth and enlargement of the side valleys indicates the degree to which the postglacial stream drainage has attained readjustment to the accordant slopes normal to purely stream-erosion and weathering cutting of valleys.

The morainic loop. Continuing up the trough valley there is next encountered the *morainic loop* or terminal moraine accumulation developed at the end of the Onondaga lobe during the halt period. This is at once the most conspicuous and spectacular feature of the glacial series, for it blocks the valley completely with a massive earth barrier. Its inner or northern side, against which the ice end rested, is so steep as to make it a very noticeable topographic feature.

Plate 3 shows this steep front as viewed from the west end of the moraine itself; plate 9 is a view also from the west side of the valley but from a point farther north along the Onondaga trough side, and therefore shows better the general configuration of the mass. The moraine makes a vast amphitheater of the head of the valley on its north side, with sides 300 feet high in the steeper upper part and a further slope of 200 feet more in the gently inclined portion at the base.

Against these slopes the ice tongue rested while discharging the material forming the moraine. The form of the slopes may, therefore, be regarded as a mold of the form of the ice itself for the depth up to which the moraine stuff was banked against its front. Beginning at the elevation of the relatively level crest line of the moraine, the ice is to be conceived as rising steeply northward, and within a few miles attaining sufficient thickness to fill the trough valley to the height of its bounding walls. This would mean that near the moraine front there was an ice slope of perhaps 400 feet down to the moraine summit.

The terminus of the lobe would thus have a very distinct wedge-shape, convex on both sides, like the blade of an axe made very thick behind the edge, the horizontal front edge of the wedge being disposed always along the crest line of the moraine during the progressive stages of its upbuilding in mass and height. Blocks of rock, melting out of the ice above the level of the crest at any stage, would roll and slide down the steep frontal slope of the ice until they lodged on the moraine; melting water would wash down the finer gravels and sand; drainage in streams of considerable volume at each margin of the lobe would sweep down larger quantities of such material; and probably there was also upturning of the bottom ice layers so that these deposited their burden of débris on the inner side and on the crest of the moraine during its upbuilding.

The major portion of the material comprising the visible structure of the moraine seems to have been débris carried in the upper layers and on the surface of the ice lobe and aided in attaining its final position on the moraine in some degree by water transportation. Enormous volumes of water were continually being freed by the ice melting, not only at the lobe-end but also for a considerable area back from the front. Accordingly, it is not surprising to find that the superficial portions of the moraine are largely made up of water-sorted materials, sand and gravels coarsely stratified. On this account, too, the moraine, especially on its west side, has a distinctly kame structure. On the east side where the view shown in plate 4 was made, a much more characteristically ice-deposited hummock surface is found, and the cultivated field of the foreground of this picture shows the typical *boulder-clay* composition of such accumulations.

Kame kettles and hummocks. In a *kame moraine* the knobs and kettles are typically much more conspicuous than the similar hills and hollows resulting from direct ice-deposit of the glacial débris. The Tully moraine on its west side, as has been noted, has a kame structure and it also exhibits, especially along its south front, very strikingly and characteristically the *knob and kettle topography* of such accumulations. Indeed, few finer examples of this phenomenon could be found in all the accumulations of continental glaciation than occur in this section of the Tully moraine.

In origin the kettle or hollow, rather than the knob, is the determining factor of such topography, and the history of these hollows is another significant link in the chain of evidence connecting all the phenomena found in the region with the glacial invasions. As the moraine accumulated, deposit along the front of the ice was frequently much more rapid than the melting of the ice of a particular area. Hence it commonly happened that a block of ice was buried deeply under the gravelly débris. In such position it was effectively protected from melting as quickly as did the exposed ice areas adjacent to it. In time the buried block was completely detached from the ice tongue and persisted, unmelted, while additional masses of deposit were piled around and over it. When the detached ice blocks finally melted away completely the deposits over it must have sunk down to fill the cavity thus created. Such burial, melting and slumping must have constantly occurred while the moraine was forming,

Plate 9

Tully moraine loop, inner side. View from slopes of Dutch hill, lying off to the northwest from the moraine. Note the salt-well derricks on both sides of the valley at the base of the moraine. Summit of moraine made more distinct by retouching photograph.

Plate 10

Kame kettle on west side of south front of the Tully moraine. Coarseness of the material composing its walls is indicated in the photograph.

but the resulting hollows were then almost at once slushed full of other sediment. But during the very last period of the maintenance of the ice front at the moraine, the buried ice blocks apparently persisted until after deposit had ceased, and, on their melting out, the overlying débris caved in and formed the kettle hollows that are now so distinctive a feature. The material between one and the next of these, having a solid foundation, kept its original height and now forms the knobs of such topography.

One of the kettles, lying directly off to the north of the improved state highway crossing the south face of the moraine, is illustrated in plate 10. It is difficult to photograph such depressions so as to give a true expression of their shape. Thus the depression shown in plate 10 is almost circular and its foreground slope is nearly as steep as that of the background. The man stands at the bottom of the pit and his figure gives some notion of the scale; the hollow is approximately 75 to 100 feet deep. This one, and most of those on the upper levels of the moraine, contain no water; for the walls and bottoms of these are made up of such coarse material that drainage into them escapes under ground as rapidly as it enters. plate 11, however, illustrates a smaller kettle of the same origin, lying to the south of the road, in which water collects, because the finer clayey sediment found on these lower slopes of the moraine front is more impervious to downward percolation of precipitation.

South front of the moraine. Plate 12 is a view of the south front of the moraine from a point some distance up the slope of the valley wall on the west side. The gentle undulations of the cultivated fields and intervening forest areas, occupying the middle distance of the picture, are characteristic of the topography of this side of the accumulation. Here the material slid and slumped away from the crest of the moraine; much of it probably having the consistency of a wet concrete mixture at the time of deposit and therefore tending to build up a much gentler slope than that which marks the inner side of the moraine where the deposited material rested against and was supported by the ice during its shaping. This south-facing deposit, while occasionally sandy, has on the whole a much finer texture than that of the inner northern side; hence it is much better adapted to cultivation, and is the site of fine farms.

Lake overflow channel. When the ice front began to be melted back rapidly from its position at the moraine a great hollow was created between its retreating margin and the inner side of the moraine. Into this hollow water from the melting ice and from the drainage of the adjacent valley sides poured until the hollow was filled up. This water could not escape northward, for there all the country was still solidly mantled by the glacier hundreds of feet thick; it could not escape laterally for the valley sides rose to elevations of 1500 and more feet. Accordingly its level was determined by the lowest hollow in the morainic barrier that had been built up across the valley and there the water of this local, *proglacial lake* overflowed to the south. To this body of water Fairchild has applied the name of Lake Cardiff.[6] The main overflow later may have been through a gap at an elevation of about 1180 feet that occurs just to the west of the road intersection north of Mud lake. But while the ice was apparently still blocking this lowest gap in the moraine an incipient lake seems already to have formed on the east side and its waters found escape through a gap at 1260 feet height, for the stream of this overflow made a very distinct and typical channelway, now altogether dry, parallel to the improved state highway leading north, just outside the village of Tully Center. On the topographic map this lake *outflow channel* is indicated by a tonguelike curve northward of the 1260 foot contour line. It is immediately parallel to the state road and is illustrated by plate 13, looking south.

The channel is seen on the left side of the picture and its cross-section form is most clearly discernible in the part between the barns on the right and the road on the left. Its right bank is in the loose morainic stuff and is most typical; the other bank is against the rock of the valley side.

The wide flat bottom and the low, though steplike, bank on the right are characteristic of such channelways. While functioning they flowed a stream of large volume continually replenished by the ice melting, which swept along its course in much the same way that the upper Niagara river on a larger scale now discharges the drainage of the Great Lakes. In the present instance the current was not so clear as is the Niagara water for it was derived from the ice-front immediately at hand, and this furnished a large quantity of sediment that was carried out of the small lake before it could settle to the bottom. Perhaps it would be better to class this scourway with what are termed *marginal* or *morainic channels,* for the ice influence and the sediment load the ice furnished no doubt gave it the predominating characteristics of this class, but, in its later phases at least, it must have had a lake fore-bay, hence may properly also be called a lake outflow channel.

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[6] Fairchild, H. L., Glacial Waters in the Finger Lakes Region, Bul. Geol. Soc. of Amer., 1899, 10: 57–58.

Plate 11

Smaller kame kettle with standing water on lower slope of front of Tully moraine

Plate 12

South face of the Tully moraine. The village of Tully (not "Tulley Valley" or "Tully Center") is marked by the church steeple on the far side of the picture to the right of the center of the view. Note the gentle undulating slopes of this face of the moraine deposit.

Plate 13

Lake outflow channel on east side of Tully moraine. Leads down to village of Tully Center. Improved state highway leading to Syracuse on left. Note flat bottom and steplike bank on right in middle distance.

Outwash deposits. While vast quantities of the glacial débris brought forward by the Onondaga valley lobe were deposited in the moraine, as the vast bulk of this testifies, still more material was probably carried forward and southward by the waters released at the melting end of the ice and those which flowed along its lateral margins; for all the valley to the south of the morainic front is deeply filled with stream-sorted gravels, sands and clays, extending up to the levels of the moraine base at its south front and sloping thence gently southward for many miles. Thus was formed a vast *outwash plain* and a *valley train* that follows the course of the Tioughnioga river for many miles.

These deposits were formed by streams overloaded with sediment and during the same period that the moraine was being built up. On leaving the steeper slopes of the morainic front the velocity of such streams was at once appreciably diminished and they could not carry along all the detritus with which they were burdened. Accordingly, the coarsest materials, boulders and pebbles, were deposited first, and as the streams spread over their own accumulations, their flow was progressively less deep and more feeble so that successively finer deposits were laid down southward. Again, as their deposits built up their own beds and made these higher than the adjacent areas the streams were constantly shifting their channels to the lower points and building up these areas in turn. Thus eventually there was developed the wide, level plain illustrated by plate 14.

It must not be conceived that this outwash deposit was necessarily all built up from streams issuing from the ice immediately at the points where the morainic front is now seen. This morainic mass probably continues under the outwash for considerable distances southward and may indeed be made up of a number of ridges marking earlier halts in this section, as the visible mass marks the last stand. These possible and probable earlier corrugations of morainic material are, however, now all veneered over and buried under outwash. They must of course have been lower in elevation than the visible morainic mass at Tully, else they could not have been buried completely. But during the existence of each halt an apron of outwash was deposited along the moraine front, and as a succeeding, more northerly ridge was built up its outwash in turn filled in behind and built up over the deposits of both morainic and outwash material made previously.

Pitted plain lakes. Such composite and progressive development of the outwash deposits gives the clue to the origin of the singularly interesting and beautiful lakes, the Tully group and Little

York lake, that now occupy a considerable portion of the outwash plains. Part of Crooked lake of the Tully group is shown in plate 15; Little York lake appears in plate 20. As in the case of the kettles in the kame section of the Tully moraine these lake basins are the result of the melting out of buried ice blocks and the subsequent settling down of the superimposed material. Here the blocks seem to have been tabular in form, though irregular in outline, probably wide thin wedge-ends of the ice very quickly and deeply covered by the morainic and outwash accumulation. That such deductions are not wholly theoretical will appear on inspection of plate 16, where *pitted plain lakes* are actually in process of formation on a diminutive scale at the front of an Alaskan glacier. If one will recall how easy it is to store ice through the summer under only a thin cover of sawdust, it will be understood how ice blocks, detached from the glacier front, might persist for long periods under deep deposits of earthy material. In fact, experiments made on the surface of glaciers show that under even a slight rock cover the ice melts down only about two-thirds as fast as it does where freely exposed, a condition which gives rise to the phenomenon of glacier tables on many glaciers. These consist of an ice pedestal supporting a tabular fragment of rock which has protected the ice below from melting down as rapidly as the surrounding area.

The lakes in the Tully outwash plain are all shallow, as might be expected, but they have steep, though low shores. While the shores have not persisted through postglacial times in the perfection probably given them originally by the faultlike breaking down exhibited along the edges of such lakes in the Alaskan instance, the feature is still noticeable and is another point in support of this theory of their origin.

The several lakes are scenic features of much charm and in years before the vogue of motor travel were summer resorts that attracted numerous cottagers. While they continue to function in this way in some degree the upper ones now also serve another economic purpose. Water is piped from them through the Tully moraine and on the lower slopes of the moraine flowed into wells which have been drilled down to the salt strata in the bedrock. As saturated brine the water is pumped out of the wells and then conveyed by gravity flow to the notable chemical industries of Syracuse adjacent to Onondaga lake. This brine is the basic raw material for these industries. The continuous gravity movement of the liquids that the topographic relations make possible is a geographic factor of more than small importance in the success of the industry.

Plate 14

Tully outwash plain. View from the east side, looking south from the improved state highway on the lower slopes of the south face of the moraine.

Plate 15

Crooked lake of the Tully Lakes group. As seen from the valley side on the west. Occupies a depression in the outwash plain, which extends across the picture to the east valley wall. A glimpse of Big lake is visible in the distance.

Plate 16

Pitted plain lakes forming in front of the Hidden glacier, Alaska, 1905. Note the level surface of the outwash deposits and the breaks where the gravels have slumped down, due to the melting out of buried ice. In the bottom of some of these lakes unmelted parts of the ice blocks could be discerned.

History of the Tioughnioga river. Up to this point the discussion, with the exception of the emphasis put upon the notable succession of the glacial series features found in the area and the regional descriptions, has not involved anything especially novel in the interpretation of glacial phenomena or physiographic history. The reader has, however, now been sufficiently informed in regard to the general succession and relation of the features exhibited, to be in a position to appreciate a set of conditions which have given the course of the Tioughnioga river peculiarities that have unusual significance in the interpretation of the last phases of the glacial development of the area.

The Tioughnioga river has its source in Big lake of the Tully Lake group. Probably Crooked lake and Long lake also underdrain to it, for they stand at a slightly higher level than does Big lake. Reference to the topographic map will reveal the fact that almost immediately after leaving the Big lake source the course of the river bends sharply over to the east valley wall of the outwash plain and continues to parallel the valley side for several miles. In this section, parallel to the valley and alongside the improved state highway, the river cuts directly into the rock wall of the larger depression. Then the stream passes through Little York lake, meanders for some miles over the valley train deposits and next, opposite Homer, it again swings sharply against the east valley wall. What is the significance of these two swings with a course close up against the bedrock of the valley side in each case?

Reference to the photograph of the relief model of the region (plate 1), in conjunction with use of the topographic map will make it evident that the place where the first of the swings occurs is just opposite the mouth of the Otisco lake *through valley,* marked at its end by the village of Preble. Similarly the swing at Homer is the end of the Skaneateles lake through valley. Both of these lake valleys have a history equivalent to that of the Onondaga valley. They are glacially eroded troughs even more deeply and sharply incised by the ice than the Onondaga valley.

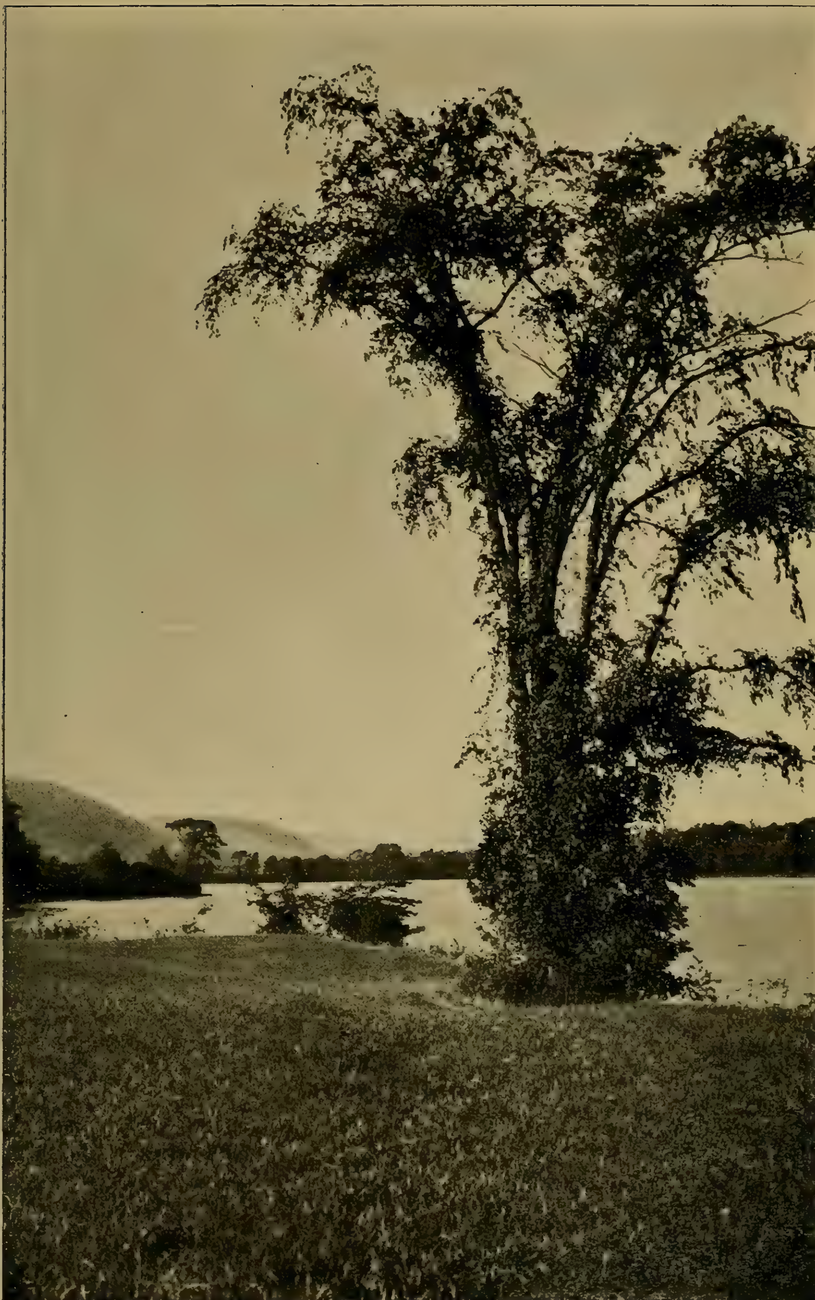
Apparently, also, they were occupied longer by the ice than was the Onondaga valley. This might be expected since they were more directly in line with the axis of the ice advance, as pointed out earlier, and were cut deeper and straighter; hence they could hold a more actively supplied and deeper lobe of ice during the retreatal stages. But more significant than such inferences is the fact that beyond the south end of each of these valleys there is spread a wide fan of outwash material, which lies higher on the west and slopes off in alluvial-fan shape across the Tioughnioga valley. Because such filling, then, makes the valley bottom highest on its west side the course of the stream is pushed sharply over against the east side of the valley and made to outline the form of the fans on the north and south. The deposit at Preble is clearly shown in plate 18 where it is seen rising with relatively steep slope up the valley opening in the center of the picture.

In other words, after the outwash from the Tully lobe had been built up to its maximum level, heavy outwash deposits were still being brought out of the Otisco and Skaneateles valleys and dumped on top of the Tully outwash plain where these valleys had outlet to this plain at their south ends.

It may be argued that these deposits are of postglacial date, and hence that the pushing of the Tioughnioga stream against the east side of the valley may also have been a recent occurrence and not contemporary with ice-waning phases of the glacial occupation. Such a deduction is, however, opposed by several lines of evidence.

If of postglacial origin the deposits at the mouths of the valleys would nevertheless need to have been stream-transported. Yet there is no drainage down the southeast slope of the Otisco valley ending at Preble at all competent to build up such a mass. The small stream that does emerge from the valley is apparently itself guided in its course by the outwash accumulations, for it skirts their south edge and empties into Little York lake. While this applies with less force to the conditions at Homer, for Factory creek is evidently a stream of sufficient length and volume to transport considerable sediment, sufficient proof that it did not make this deposit is found in the fact that Factory creek is an eroding, and not a depositing, stream in this section and has cut a notable channel through the outwash itself; is, indeed, engaged in clearing it away.

Finally, the nature of the channel of the Tioughnioga stream itself gives evidence that it was developed under different conditions from those that now prevail. On comparison of plate 19, which shows the Tioughnioga river in the section where it is forced to flow close to the east valley wall (on the right), with plate 13 of the abandoned lake outflow channel across the Tully moraine, it will be perceived that these have essentially similar characteristics. The Tioughnioga river in this section has the channel peculiarities of a lake outlet stream, and such indeed it is. But the existing stream is "underfit" (to use a word coined by Prof. W. M. Davis of Harvard) in that it flows over the bed of the channel in wide shallows and has not, under the existing conditions, either the volume or the



Shoie of Crooked lake, west side. Illustrates low, but steep, descent from outwash plain level to lake surface.

Plate 18

Otisco valley outwash fan spreading over the Tully outwash deposit. The Otisco fan occupies the valley opening in the background of the center of the picture. The view looks over the northeast arm of Little York lake. The village of Prable is situated just at the base of the rock hill at the extreme right in the picture.

Plate 19

Tioughnioga river where forced over against the East valley wall by outwash from the Otisco valley. Note the broad, flat-bottom nature of the channel and its gentle gradient and the evident "underfitness" of the present stream which covers the channel bottom with only a shallow current.

Plate 20

Truncated spur between south end of Otisco valley and Tioughnioga valley. Truncated part is the steep forest covered slope, back of expansion of northeast arm of Little York lake, which appears in the left center of picture.

velocity to carve out the depression it occupies in part. The lakes which are the source of the present stream are of sufficient area to equalize the rainfall run-off discharge of their drainage area so that the stream does not fluctuate between flood and drouth as would normally be the case with a stream not having such storage reservoirs at its head. Hence it may be assumed that the stream never fills its wide channelway to the banks, as indeed is evidenced by the fact that very low bridges have been built across it, houses placed near the water's edge and that forest trees have grown up in the channel bottom.

It appears, therefore, that the Tioughnioga channel in this section was formed when the stream carried a much larger body of water, that is, when it was fed primarily by the outflow from the Cardiff lake, ponded behind the Tully morainic barrier. This water was probably relatively free of débris when it reached the part of the Tioughnioga course under discussion but here it probably received accessions of sediment-laden water coming over the Otisco outwash. At a later date this water, too, may have cleared up on becoming the outflow of the highest level lake in the Otisco valley and the combined volume of two such large drainage basins would suffice to create a stream of considerable magnitude, one that could amply fill the channel from bank to bank and scour out a typical flat-bottom lake outflow course.

Truncated spurs. One feature of the topography due to the glacial occupation yet remains to claim attention. This is the conspicuous facetting of the slopes of spurs that formerly projected with rounded shoulders into the main valley, but which have been planed off by the ice erosion so that the through-valley Onondaga-Tioughnioga depression now has a straight line course. On the topographic map the *truncated spur* phenomenon is well illustrated by the east side of Toppin mountain across the valley from Preble and again on the spur to the north of Preble. In the photograph (plate 20) are shown both the upper end of the Tioughnioga (south continuation of the Onondaga valley) valley (on the right) and the south end of the Otisco valley (on the left) with the rock hill of the divide spur rising between them. The summit and the hollow on the south side of this spur, the lee slope with respect to the glacial onset, preserve, essentially, the preglacial contours of the country in their soft, rounded, mature curves. The east end, however, has been abruptly cut off, as though sliced through with a huge knife, and this is a characteristic feature of such spurs where they were affected by the ice scour. While difficult to photograph effectively, such spurs are a very conspicuous element in the scenery of the area and arrest the attention of even the casual tourist.

Conclusion

The above account by no means includes all the interesting features of the physiography of the region. A whole bulletin might well be devoted to tracing the preglacial, glacial and postglacial drainage history of the area. But this paper will have served its purpose if it has brought to the reader a realization of the extraordinary variety of glacial phenomena the section exhibits, all of typical and even magnificent development, and within very narrow areal confines. With the one notable exception of *eskers,* every significant development due both to the erosional and depositional work of the continental glaciers is here visible, and not only that, but also among surroundings of the greatest scenic attractiveness and in situations immediately accessible from the State's improved highways. It is hoped that the publication of this paper will help to make the area deservedly well known to increasing numbers of those who wish to understand as they go.

PALEONTOLOGIC CONTRIBUTIONS FROM THE NEW YORK STATE MUSEUM

BY RUDOLF RUEDEMANN

The following notes are written to direct attention to some of the observations of broader interest made by the writer in recent years, mainly in connection with the monographic treatment of the Upper Ordovician of New York;

They deal with the following subjects:

1 Homoeomorphic development of so-called species and genera of Graptolites in separate regions
2 On sex distinction in fossil Cephalopods
3 On some cases of reversion in Trilobites
4 On color bands in Orthoceras
5 A new Eurypterid from the Devonian of New York
6 Preservation of alimentary canal in an Eurypterid
7 Note on Caryocaris Salter
8 Fauna of the Dolgeville beds
9 Additions to the Snake hill and Canajoharie faunas
10 The age of the Black shales of the Lake Champlain region
11 The Graptolite zones of the Ordovician shales of New York

1 Homoeomorphic Development of So-called Species and Genera of Graptolites in Separate Regions

We wish to state here a clear case of the development, in the same direction but in separate regions, of several forms from a common species.

The axonophorous graptolite Glossograptus quadrimucronatus has a worldwide distribution. It was first described by James Hall[1] from the Gloucester ("Utica" shale) of the Lake St John district in Labrador, but is now known from numerous localities in eastern Canada and New York, as well as from Scandinavia, Great Britain and Australia (Victoria). In the Lake St John district the type form occurs in beds of late Utica age, and in New York this form is found in the Atwater and Deer River shale of late or post-Utica age. In Europe it occurs in beds of

[1] For bibliography, see Ruedemann, Graptolites of New York, pt. 2, 1908, p. 385.

about the same age (zone of *Pleurograptus linearis*). Earlier mutations appear in New York in beds of Trenton age (Canajoharie and Schenectady beds). One of these is characterized by two long spines at the sicular end (mut. *cornutus*).

In *Glossograptus quadrimucronatus* all four sides or edges of the prismatic rhabdosome are furnished with a row of spines each, two spines flanking each aperture. These spines are of nearly equal length throughout and were obviously a protective measure.

The Utica shale at Holland Patent and South Trenton has afforded a peculiar mutation that is characterized by spines of double length (2 mm +) that are found opposite the sixth or seventh pair of thecae, sometimes also opposite the fifth to seventh pair. In this peculiar character the form exactly corresponds to the var. *spinigerus* Lapworth of *Glossograptus quadrimucronatus* (see Elles & Wood, p. 223), which singularly enough occurs at the same horizon, that with *Pleurograptus linearis* in the Hartfell shales of Scotland. In this vicarious form of Scotland, however, the longer spines appear at about the tenth pair of thecae. A third form has been described by T. S. Hall (1906, p. 277), from Victoria, Australia. This has four prominent spines about 2.5 mm long at about the seventh or eighth thecae.

Fig. 1

Fig. 2

Fig. 3

Figs. 1–3 *Glossograptus quadrimucronatus* (Hall). Fig. 1: Mutation from the Utica shale at Holland Patent, N. Y.; fig 2: The variety *spinigerus* Lapworth (from Elles and Wood); fig. 3: Mutation from Victoria, Australia (from T. S. Hall).

A fourth mutation has been observed in the Utica shale of Herkimer county, in an earlier horizon than is exposed at Holland Patent In this form, in which the rhabdosome is abnormally large, the longer spines (over 3.3 mm long) correspond to the seventh to ninth pair of thecae, in the specimens observed.

We have thus four mutations of Glossograptus quadrimucronatus which appear at about the same time and which are all distinguishable by one or several rings of greatly lengthened spines, some distance from the sicular end. When less closely observed, all four would be readily taken for one or the same mutation. The Holland Patent mutation bears, however, the longer spines at the fifth to seventh thecae, the Herkimer county form at the seventh to ninth pair, the British form at the tenth pair and the Australian form at the seventh or eighth pair.

It is not possible that the Herkimer county form is identical with either the British or the Australian one, for it still differs from both though less widely than the Holland Patent form.

There are thus four different mutations of the species which have developed at practically the same time in the same direction, namely, the enlargement of a ring of spines. In Great Britain there occurs, further, a very closely related species, Orthograptus pageanus var. abnormispinosus Elles & Wood which, at the same time, also bears a ring of four longer spines, at a similar distance from the sicular end.

There existed thus some stress or tendency which led independently in widely separated regions to the development of similar or homoeomorphic mutations which, however, are not identical, as proved by the slightly different location of the rings of spines. If by accident, the rings had appeared at the same level of the rhabdosome, those mutations would be indentical although they had originated independently and separately in different regions, as proved by the fact that they do not occur together in any of the regions, which, in that case would constitute the center of distribution. One naturally asks, Have such cases not happened oftener and the forms been thrown together into one species of wide distribution, because the original differences, denoting independent evolution, have failed of observation? It would then seem possible that even the same species (or what to our crude discernment appears as one species, but really is not), may at times have originated in several separate regions independently, a possibility that has been repeatedly denied by students of the principles of evolution. It would be only necessary, it seems from the case here described, that a species of worldwide distribution, be exposed to the same influence or stress at separate places and then respond in exactly the same manner. It could also be urged that there might have existed a tendency to a development of these longer spines, which made itself felt at different places, but this assumption is negatived by the fact that the mutations here mentioned did not persist at all, but disappeared again as suddenly as they had appeared. They are therefore more probably of the nature of devices to increase the equilibrium or the floating surface of the rhabdosome; devices that, however, were impracticable in other regards and thus led to aberrant types.

The case here described of the independent development, in separate regions, of forms that might be brought together as one mutation and even as a new species, is but the expression in a smaller way of a process that, acting in diverse regions upon numerous species, has led to the evolution of polyphyletic genera of graptolites.

The heterogenetic, homoeomorphous development of the most important genera of the Dichograptidae from Clonograptus and Bryograptus successively through Dichograptus, Tetragraptus to Didymograptus has been early recognized by Nicholson and Marr and their phyletic lines of species have been traced by Elles in the case of the British species through these "genera" and by Ruedemann for the American species. The result of these investigations is that the genera Clonograptus, Bryograptus, Dichograptus, Tetragraptus and Didymograptus are undoubtedly polyphyletic; and represent stages of parallel development in many "phyla" or genetic lines of species (see p. e. table of New York State Museum Memoir 7, opposite p. 554) showing the phylogeny of the species of American Axonolipa or earlier graptolites without axes, leading from multiramous irregularly branching forms (Clonograptus, Bryograptus) through multiramous regularly branching forms (Dichograptus) to pauciramous symmetric forms (Tetragraptus and Didymograptus). The explanation for this remarkable parallelism is sought in the suggestion that symmetry in the arrangement of the branches would tend to insure an equal supply of food to each branch, and that the fewer the branches the greater the supply of food to the entire organism.

As in the case of the mutations of Glossograptus quadrimucronatus described above, also the development of the homoeomorphous groups of Dichograptus, Tetragraptus and Didymograptus has been going on independently in the various oceanic basins, or even different parts of the same basin; as is suggested by the different genetic lines observed in eastern North America and in Great Britain. Nevertheless the new "genera" seem to appear at the same time in the different oceans and the development to be thus strictly parallel and everywhere persistently in the same direction, namely, toward less branches and more symmetric colonial stocks.

This development of the Lower Ordovician axonolipous graptolites is thus typically orthogenetic, as the result of persistently acting exterior factors such as the advantages of equal distribution of food to all branches and the attainment of equilibrium of the floating rhabdosome by symmetric and uniform development of all branches.

The present writer has distinguished ten lines of development of graptolite species among the New York forms from Clonograptus and Bryograptus through Tetragraptus to Didymograptus, which can be traced to at least four different species of Bryograptus and Clonograptus (Goniograptus). There should then be recognizable here and in time named at least four generic groups of Tetragraptus and ten of Didymograptus.

Taking our example of the Lower Ordovician graptolites of New York, we get the following phylogenetic diagram of these earlier graptolites.

It would lead to a bewildering and complex nomenclature if we should attempt to recognize all these racial lines and stages by sep-

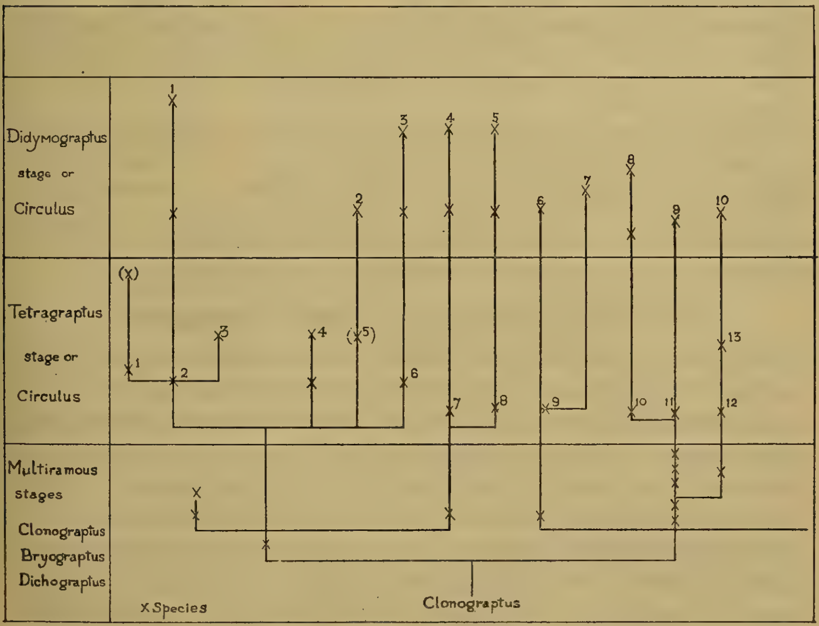


Fig. 4 Phylogenetic diagram of the American axonolipous graptolites; the figures representing the number of species.

arate names, as an attempt to do so in the case of the goniatites has shown, but it would be perfectly possible to name each racial line by its terminal member, as line 1 of our diagram that of Didymograptus forcipifer, and retain for practical reasons the polyphyletic "genera" Tetragraptus etc. with the understanding that they are not true genera. The writer has proposed (in Memoir 7, 1904) to term them "Geologic genera," while Gregory's better term "circulus" has come into use for these groups of homoeomorphs.

Similar conditions seem to prevail also among the axonophorous graptolites where the genera Diplograptus, Climacograptus and Monograptus apparently fall into racial lines.

We have then here the same phenomenon of polyphyletic development of "genera" so well known from the ammonites and brachiopods through the investigations of Buckman and others, and also recognized among the vertebrates, as in the case of the development of the horses in America and Europe.

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2 On Sex Distinction in Fossil Cephalopods

The upper Utica shale at Holland Patent contains in close association in the same bed, three different forms of breviconic cephalopods, namely, a larger and a smaller form with contracted apertures and a smaller form with open aperture. According to the usual procedure, these would be distinguished as different species; the first two as belonging to Oncoceras, the third as a Cyrtoceras.

The fact that both the larger and smaller forms with contracted apertures exhibit more closely arranged septa just below the living chamber, indicates that the contracted aperture actually indicates a gerontic condition and that both forms, the larger and smaller, had reached or passed maturity. Outside of this difference in size, the two forms agree absolutely in all other characters, as relative rate of growth, depth of septa and camerae; and likewise does the third form with wide open aperture fail to exhibit any other differences suggestive of specific separation. This third form is also of smaller size.

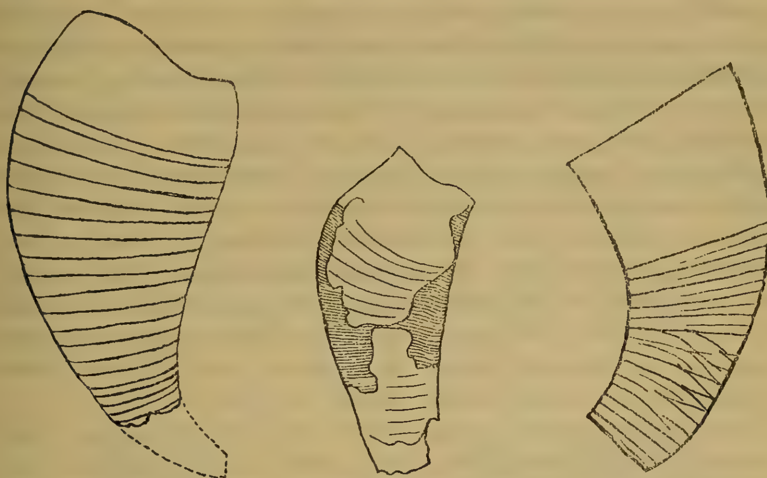

Fig. 5 Fig. 6 Fig. 6*a*

Figs. 5–6*a* Oncoceras pupaeforme nov. Fig. 5 Mature female; fig. 6 Mature male; fig. 6*a* Immature female.

We consider these three forms as belonging to a single species (to be described in a later publication as Oncoceras pupaeforme n. sp.); the larger and smaller forms with contracted apertures representing the mature females and males, and the smaller forms with open aperture the immature females.

The conclusion that the larger shells contain the females of the species and the smaller ones the males, is based on the observation that in the cephalopods (E. Ray Lankester, V, p. 319), " as a rule the males are more slender (e. g. Loligo media) or smaller than the females." In Argonauta, where the maximum of sexual dimorphism is found, the females are as much as 15 times as long as the males.

In Nautilus, which would be the nearest relative among recent cephalopods to use for comparison, the difference between the conchs of the two sexes seems to be still subject to some doubt. Bashford Dean (1901, p. 819) describes the shells of the females as frequently a little more arched and ventricose than those of the males, while Willey, on the contrary, considers the narrower and higher shells as the female ones. Other authors (see Ray Lankester, loc. cit.)

describe these cephalopods as larger and the aperture of the shell as wider in the male than in the female.

Emphasizing the general observation of the larger size of the females among the cephalopods, we incline to accept Dean's view and especially do not believe that the doubt still expressed as to the relative size of the shells in Nautilus militates against our conclusion that the two different sizes of the mature conchs in Oncoceras pupaeforme can be ascribed to sexual differences and that the larger form most probably represents the female. D'Orbigny, noticing that there were two varieties of almost every kind of ammonite, one compressed, the other inflated, assumed that the first were the shells of male individuals, the second of females (see Woodward, 1910, p. 185), but Buckman and Bather (1894, p. 427) have concluded that the sexual differences in ammonites, inferred by de Blainville D'Orbigny, Munier—Chalmas and Haug are "auxologic or bioplastic rather than sexual, being in some cases phylogerontic, in others merely ephebic or gerontic."

In regard to possible sexual differentiation of the shells in the Paleozoic forms, especially the early orthoceraconic nautiloids, we have not been able to find any suggestions in the literature at our disposal, which, however, is not complete except in *Barrande's Système Silurien* (v. 2, pt 1, p. 38 ff, 1877). There the fact of the wide differences in the relation of length of living chamber to the width at the base of the same in the mature stage of a number of species is shown in tables; this difference rising in some species, as Orthoceras culter, to a threefold length of the chamber in the longer forms. While Barrande would see in these wide differences of mature development of the living chamber only individual variations in size, (loc. cit. p. 39), we consider it very probable that they also denote the sexual difference in the size of the shell in these species.

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3 On Some Cases of Reversion in Trilobites

Triarthrus spinosus was described by Billings (1857, p. 340) as characterized by a long spine that springs from the neck segment and a second one proceeding from the eighth segment of the thorax; and two long genal spines.

The writer has found this characteristic trilobite of the Canadian Gloucester shale among material from the upper Utica shale at Holland Patent, N. Y. These specimens exhibit a series of three successive spines on the axis of the eighth, ninth and tenth thoracic segments, and show further the genal spines to be inserted in a peculiar way forward of the genal angle, at a point about one-third the length of the head. Moreover the latter do not proceed backward but are curved outward at the base and slightly inward distally. Fine material of T r i a r t h r u s s p i n o s u s in the United States National Museum, indicates by the presence of spine bases that also the 11th to 13th thoracic segments bore spines. Finally, also some of the pleurae of the thorax seem to have been produced, at times, into long recurving spines; this is at least suggested by two such spines, found apparently attached to a fragment of a pleura, lying partly below a specimen.

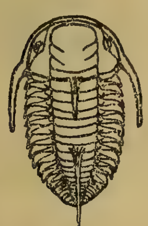

Fig. 7

Fig. 8

Figs. 7, 8 T r i a r t h r u s s p i n o s u s Billings. Fig. 7: Billings's figure; fig. 8: laterally compressed specimen (x2), showing dorsal spines (from the Gloucester shale at Ottawa, Canada; original in U. S. National Museum).

The peculiar lateral spine of the free cheek, the series of long axial spines on the posterior segments, are characters not seen in Ordovician or later trilobites, but known of certain early Cambrian forms, especially of the family Mesonacidae. Also the long nuchal spine, on the occipital ring is very strongly developed in the Mesonacidae, but rarely seen in Ordovician and later trilobites.

Triarthrus is now the only Ordovician genus of the Cambrian family Olenidae (Olenus barely entering the Ordovician in Europe) and the last of that family which in its turn appears again as a further development of the Lower Cambrian family Mesonacidae. The characters here emphasized of T. s p i n o s u s and which distinguish this last of the Triarthri (the Gloucester shale being of late and post-Utica age) from the other congeners make it thus strikingly similar to some of the earlier trilobites, as Elliptocephala asaphoides Emmons in the series of posterior axial spines; to Olenellus gilberti; O. fremonti, Eurycare etc. in the genal spines that, especially in the earlier growth stages wander forward along the margin of the free cheeks.

Inasmuch as these features are not known of trilobites in the Middle and Upper Cambrian and Lower and Middle Ordovician, it is proper to assume that in T. spinosus they are reversional and atavistic in character, using these terms in their popular meaning (see below).

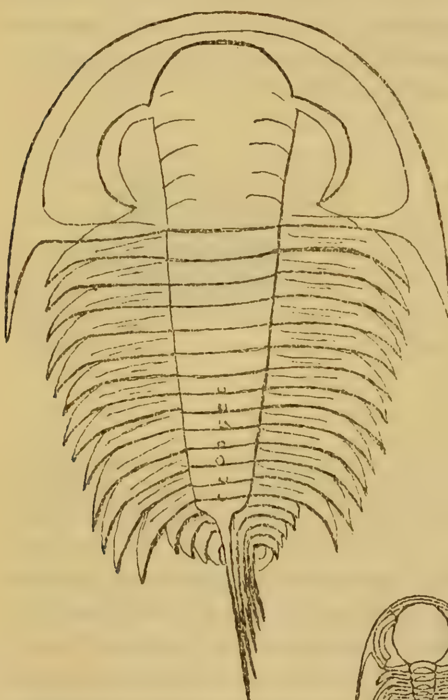

Fig. 9

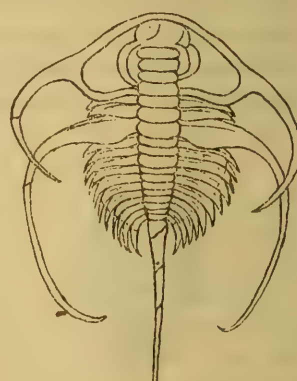

Fig. 10

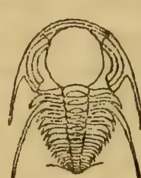

Fig. 12

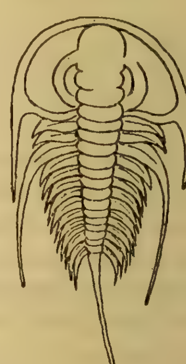

Fig. 11

Fig. 9 Elliptocephala asaphoides Emmons. Fig. 10 Olenellus fremonti Walcott. Fig. 11 O. gilberti Walcott. Fig. 12 Paradoxides inflatus Corda. (Figs. 9–11 after Walcott, fig. 12 after Barrande

Somewhat different characters suggesting atavistic tendencies have been observed by Doctor Clarke in Devonian trilobites (1913, p. 135). These consist in lateral spines on the cheeks in trilobites of the Phacops group: namely, Proboloides cuspidatus Clarke; and spinules on the basal margin of a cephalon of Dalmanites sp: this, however, being observed in but one case and not confirmed by other specimens. Doctor Clarke says regarding Proboloides cuspidatus:

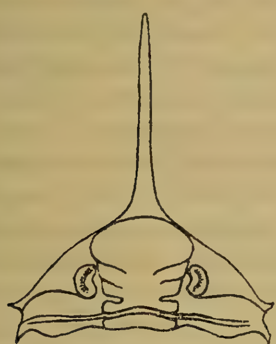

Fig. 13

Fig. 14

Fig. 13: Proboloides cuspidatus Clarke; fig. 14 Dalmanites (Mesembria) sp.? (after Clarke).

"The elemental or reversional character of this entire group is expressed here by the singular and unparalleled reappearance of spines on the lateral margins of the cephalon at the outlet of the facial sutures and as these lie above the normal position of the spines at the genal angles, each cheek thus bears a pair of spines. This remarkable structure, the significance of which is more fully estimated in another place occurs in young and mature individuals alike so that it is in no wise an indication of uncompleted ontogeny but distinctly atavistic and due apparently to the reversional tendency which has accompanied or resulted from geographic isolation."

On page 22, op. cit., it is stated of Proboloides that it presents an unexampled retention, or reappearance, of primitive structures in its sutural spinules above the cheek angles, a structure not represented elsewhere above the Cambrian. Walcott (1916, p. 237) has more recently in his monograph of the Mesonacidae pointed out the reversion of this character of the Cambrian ancestors, as seen in a number of later trilobites. He states:

"The genal, intergenal and antero-lateral spines of the cephalon undoubtedly represent the pleural ends of segments that have been fused together and greatly modified in the process. The genal spines persist in the adult of the Mesonacidae and often the intergenal spines, but only in a modified manner. The intergenal spines are seen in a later geological period in the adult Bronteus, where they might be considered as a reversion to a character of their Cambrian ancestors. Hydrocephalus appears to have an intergenal spine and in all of the Proparia (Beecher, 1897, p. 198) the " genal spine " is attached to the space within the facial sutures, and is in fact the prolongation of one of the fused segments of the cephalon, and corresponds in this respect to the intergenal spine of the Mesonacidae. Some of the species of the genus Agnostus also show spines that suggest the intergenal spine, notably A. granulatus Barrande and A. rex Barrande."

Assuming that, as the absence of connecting forms between the Cambrian and these Ordovician and Devonian trilobites suggests, the archaic characters of the later forms are not continuous with those of the Cambrian ancestors, then we would have either a reversion to an ancestral character of organs, never suppressed; or a reiterative development of organs that were apparently lost.

Biologists have of late years thrown considerable doubt on the occurrence of cases of " reversion," " atavism " and reiterative development. The law of " irreversibility of evolution " enunciated by Dollo in 1893 has been accepted by most biologists, although severely criticized by several; and Agnes Arber has lately drawn attention to a part of the broader principle recognized by Dollo, which she defines as the " law of loss." This indicates the " general rule that a structure or organ once lost in the course of phylogeny can never be regained; if the organism subsequently has occasion to replace it, it can not be reproduced, but must be constructed afresh in some different mode." Lull (1917, p. 572) would restrict the law of irreversibility of evolution to this impossibility of regaining a lost anatomical structure, defined as the " law of loss " by Arber.

An important qualification of this law is that it applies only to *actual* losses and not to *apparent* losses due to the interpolation of inhibiting factors (Arber, p. 27, footnote).

In analyzing the criticisms to which Dollo's law has been subjected on the part of botanists, notably by Errera who considered the law of irreversibility as disproved by the facts of " reversion " (" that is by cases in which a variation appears which is interpreted as an atavistic throw-back to a hypothetical ancestor, and in which some character since lost by the species makes a renewed appearance ") ; Mrs Arber found that the cases cited possess "one common characteristic which seems to annul their significance as evidence of reversion," namely, "they all relate to meristic variations in which certain organs, of which at least one already exists, suffer an increase in number" (as p. e. the stamens).

According to Arber, the hypothesis of reversion has too often been employed by morphologists in a noncritical spirit, and "the only instances of genuine atavism of which we have any knowledge are those which consist in the synthesis by hybridization of some original form which has now become split into different races by loss of factors"

Another cause of "atavism" or "reversion" is not infrequently seen among fossils where a large number of species characterizing a certain horizon (see Grabau, 1913, p. 974) will be found "in which ancestral characters occur in the adult, thus recalling species of a lower geologic horizon." "This atavism or reversion of the species to ancestral characters may often be seen to be nothing more than an arrestation of development at an immature morphic stage, when the characters of the young are like those of the adult ancestor of earlier geologic horizons."

In looking at our case of reversion in *Triarthrus spinosus* in the light of the views just recorded, it is necessary to consider separately the forward carrying of the genal spine and the posterior series of long thoracic spines.

It is obvious from the development of *Elliptocephala asaphoides* and other Cambrian trilobites, that the earlier

Fig. 15

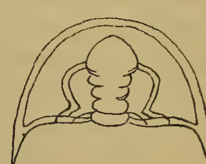

Fig. 17

Fig. 18

Fig. 19

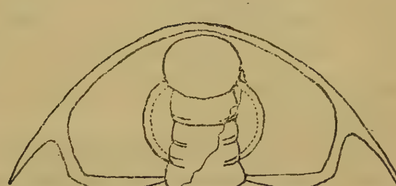

Fig. 20

Figs. 15–17 *Elliptocephala asaphoides* Emmons. Figs. 18–20 *Olenellus fremonti* Walcott. Growth-stages showing the forward position of the genal spines. (All after Walcott) growth-stages are very apt to pass through a stage with farther forward-carried genal spines than are found in the mature stage (see text-figures, 15-17 and Walcott, 1886, pl. 20). And as in the case of Olenellus gilberti and O. fremonti closely related species with normal genal spines (O. gilberti) occur associated with those with laterally placed genal spines (O. fremonti) to such an extent that Walcott formerly (1886, p. 21) considered the latter as abnormal forms of the former; and the species fremonti possesses not only in the forward position of the genal spines but also in the greater expansion of the anterior glabella characters that suggest its retarded development as compared with O. gilberti. It might thus fall under the form of "reversion" cited by Grabau. It is likewise possible that the forward carrying of the genal spine in the ontogeny was inherited in those species of Triarthrus that possessed genal spines, from the Cambrian ancestors and retained even as long as late Ordovician time in the ontogeny. The apparent reversion in T. spinosus would then, as far as the genal spines are concerned, be a further development of an ontogenetic feature retained from the Cambrian ancestors. Possessing no growth-stages of either T. spinosus or earlier Triarthri with genal spines no definite conclusion can be reached as to this character.

It is different in regard to the series of long axial spines of the posterior thorax. In this case one might feel tempted to infer that meristic variation in form of increase has taken place pointing to the axial spine that is carried on the occipital ring in T. spinosus as an inheritance of this almost ever-present organ in the Cambrian trilobites. A comparison of Triarthrus spinosus with T. eatoni and becki, that possess a continuous series of mucros on the axis of the thorax, on the one hand, and with the associated T. glaber, that is completely smooth, leaves little doubt that in the axial spines of T. spinosus we have to do with organs that were never actually lost, as shown by the series of axial mucros of T. becki and eatoni, but had become more or less submerged (entirely in T. glaber) through the influence of inhibiting factors.

It is a peculiar fact that the axial line of spines, is so prominent in the Cambrian trilobites that the genera Albertella, Zacanthoides, Neolenus, Elliptocephala, Mesonacis, Callavia, Holmia, Wanneria, Paedeumias, Bathyuriscus, Dolichometopus, Ogygogopsis and Asaphiscus contain species with rows of long axial spines or prominent mucros; while in the following Ordovician to Devonian periods this feature becomes suppressed to such an extent that, for example, in Barrande's wonderful array of Ordovician, Silurian and Devonian trilobites not a single form with this row of spines is found,[2] while Hall and Clarke (1888) found among the Devonian trilobites of New York but a single Dalmanites (Cryphaeus, namely, D. (Cryphaeus) boothi var. calliteles, one Phacops (P. cristata) and one Calymmene (C. platys) retaining faint tubercles on the axial line, and none, not even the highly spinose Acidaspidae exhibit rows of axial spines.

Now and then, however, a form will develop a single spine on one of the thoracic segments or the axis of the pygidium, as Lichas (Conolichas) eriopis Hall on the pygidium, and the strange Cyphaspis ceratophthalmus Goldfuss (see Richter, 1918, pl. 2, fig. 13) which has a single spine on the middle of the back. It is legitimate to consider these also not as new creations or reiterative developments, but as a local awakening of the dormant or latent axial spines of the Cambrian ancestors, reduced in the few Devonian forms cited above to the rudimentary vestiges represented by the small mucros. All these features, the axial series of spines or the single isolated spines, and the axial rows of mucros are thus the last traces of a character highly developed in the Cambrian ancestors and when thus appearing abruptly, as in T. spinosus or Cyphaspis ceratophthalmus partake of the character of atavisms or reversions, as popularly understood but in reality are revivals of latent characters that were never lost, and quite surely not cases of reiterative development.

The cause of this remarkable resuscitation of the axial spines, evidently once so useful to the Mesonacidae and other Cambrian trilobites, may well be sought in an adaptation or return to similar habits. Rud. Richter has lately shown in an interesting series of papers on the structure and life habits of trilobites, that many of the spinose appendages do not only serve for protection, or are merely spinose excrescences indicating gerontic condition as Beecher has urged, but had a very important function in allowing the creatures to float with little exertion in the water through the great

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[2] Among the Proetidae Astycoryphe gracilis Barrande, however, is figured and described with a row of mucros by Richter (1919, p. 12 & 13) and A. senckenbergiana R. and E. Richter with mucros on the last four thoracic segments.

expansion of their surface and the increased friction in sinking. The single dorsal spine of Cyphaspis is, for example well comparable in function to the floating spine of the zoaea of crustaceans. Taking the case of the three species of Triarthrus, associated in the Gloucester shale; they should have had according to biologic principles different habits of life to avoid the disastrous competition among closely related forms; and it is very probable that the smooth T. glaber and eatoni beckiauct.) were more active bottom-swimmers, while the long-spined T. spinosus was more given to a floating habit in a little higher level of the water.

There remain the peculiar cases of reversions noted by Doctor Clarke in Devonian trilobites of South America and by Doctor Walcott in Bronteus, Hydrocephalus and the Proparia; and expressed in the intergenal spines at the base of the head and in the lateral spines of the free cheeks. It seems impossible to consider these cases of reversion as due to arrested development at an immature stage, for Beecher's studies of the protaspis-stages of various post-Cambrian genera have failed to reveal these archaic lateral and intergenal spines in the ontogenetic development of the later genera. Nor are they cases of meristic variation, especially not the intergenal spines. There would thus remain as possible explanation for them the assumption that they also present latent characters never actually lost but only submerged for longer or shorter time by the interpolation of inhibiting factors.

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4 On Color Bands in Orthoceras

Color markings on the shells of fossil mollusks and brachiopods have attracted the attention of authors from the early days of paleontologic investigation.

The American, and some European, publications describing color markings in Paleozoic fossils have been lately listed by Roundy (1914, p. 449); the European ones by R. Richter (1919, p. 94).[3] We see from these lists that zigzag color markings on a Carboniferous Pleurotomaria were described as early as 1836 by Philips in his Illustrations of the Geology of Yorkshire, and colored Terebratulas of the Triassic in 1845 by v. Alberti in Germany. Since that time a large number of cases of color markings have been described, especially of gastropods and brachiopods, and a large proportion of these from Paleozoic beds.

The oldest case on record of color marking seems to be that of the Holopea harpa from the Chazy of Valcour Island, N. Y., described by Raymond (1906, p. 101).

While most authors have simply described the color markings as fascinating traces of the original wealth of beauty and color of the shells that has been lost to us through their bleaching, some of the more recent publications, notably those of Kayser (1871), Steinman (1899), Deecke (1917), Oppenheim (1918) and Richter (1919), deal with the bearing of the mode of sedimentation and other factors on the retention of color markings, on possible conclusions from the coloring upon the facies and the origin of the coloring. Notice of their conclusions will be taken in another place.

We shall restrict ourselves here to the cases of color markings in certain Ordovician cephalopods and make our specimens the subject of a separate note mainly for the reason that their mode of coloration seems to bear directly on the question of their mode of life.

D'Archiac and Verneuil as long ago as 1842 described a specimen of Orthoceras anguliferum from the Devonian at Paffrath, Germany, with "a beautiful chevron pattern." Marsh records (1869, p. 326) that in 1865 he procured a second specimen

[3] A complete list, including the numerous cases of mesozoic and tertiary shells with color markings has been given by R. B. Newton in 1907, a large list of color markings on fossil gastropods, brachiopods, pelecypods and one cephalopod was given by Kayser (1871, p. 265).

of the same species, while in Germany, with similar zigzag bands of the original color. They are associated there with gastropods (Natica subcostata), also bearing color markings. In the same note Marsh also states that in several instances he had found "distinct traces of the original color, arranged in delicate cancellated patterns" on "cephalopods from the Trenton limestone of New York, especially Endoceras proteiforme Hall." He further records "indications of color markings" in "Orthocerata from the Hudson and Niagara limestones of Illinois and Iowa."

Barrande has figured and described some fine examples of color markings in Paleozoic cephalopods, a fact that seems to have been entirely overlooked by the other authors. In volume 2 (pl. 108-244, 1866) of his Systême Silurien de la Bohême, he figures on plate 155, figures 6 and 7, a spotted Cyrtoceras (C. maculosum); on plate 208, figure 21, a Cyrtoceras veteranum with sharp zigzag lines ("chevrons"), and on plate 240, figure 11, a Cyrtoceras decurio with beautiful zigzag transverse bands. All these are from étage E (Silurian) of Bohemia.

Blake (1882, p. 291) describes Orthoceras annulatum Sowerby from the Wenlock limestone with colored longitudinal bands.

Foerste, in a paper just published (1920, p. 212) has a note on "Orthoceras with vertical color bands." He states:

In a specimen of an unknown species of Orthoceras found at the top of the Plattin limestone at Conn's Ford, vertical color banding is present. The specimen is 22 mm in width. The color bands equal or slightly exceed 1 mm in width and are 1 mm or slightly less apart. The color banding is a feature characteristic of the inner layers of the shell and is seen best where the surface of the shell has weathered away.

Orthoceroid shells with vertical color bands are known also at other horizons. In the Lorraine formation in the river bed west of Weston, Ontario, vertical color bands occur in an Orthoceroid shell 22 mm wide, having a siphuncle with nearly spherical segments (Loxoceras ?). About eight vertical color bands occur in a width of 5 mm, the width of the color bands and that of the intervals between being about the same.

In similar species (Loxoceras?), from the Richmond formation at the Clay Cliffs on the eastern shore of Manitoulin island, the vertical bands are about 1 mm in width and are separated by intervals varying from 1 to 2 mm where the diameter of the shell equals 15 mm.

In Orthoceras trusitum Clark and Ruedemann, from the Guelph at Rochester, New York specimens occasionally show color banding. In the specimen represented by figure 2 on plate 13 of Memoir 5, New York State Museum, 1903, there are nine or ten vertical light brown bands in a width of 3 mm. In the specimen represented by figure 9 the structure usually accompanying color banding is present, but there is no distinctive color here. This structure consists in the space between the color bands being composed of a less dense and more readily weathering material than that forming the color bands.

In all cases of color banding observed by the writer the color banding consisted of various tints of brown.

The present writer has before him four splendidly preserved shells of a Geisonoceras from the Trenton limestone, that retain the color markings. Two of these were taken from a block of dark-gray, very fossiliferous limestone obtained at Watertown, N. Y., and the two others came from the very dark-gray, highly fossiliferous upper Trenton limestone at Middleville, N. Y. The former appear to retain even the original color. These specimens have been known to the writer for many years and they were kept with material to be used in a monograph of the cephalopods of the Trenton group.

This form, before us, has been described by Hall (1843, p. 205, 209) both as Orthoceras strigatum and Endoceras proteiforme var. tenuitexum. In the former case the surface has been weathered between the darker color bands leaving the latter as " the flexuous elevated longitudinal lines " which gave the form its name; in the latter the extremely delicate, cancellated surface sculpture is preserved and the color bands lost. The name O. strigatum would have the right of priority by virtue of its earlier description in Hall's work according to the strict application of the rules of priority, but in this case it would lead to the retention of a distinct misnomer, for the strigate or fluted character of the surface is but the result of weathering. We will therefore retain the better known name Geisonoceras tenuitextum (Hall) for the species.

The character now, which to us is the most important at present, is the presence of the color bands on one side of the conch only. In the specimen reproduced in text figure 21, which has a diameter of 16 mm, the color bands number 17, are .5 mm wide, brown and separated by interspaces, averaging .4 mm. Toward the side the bands become more widely separated, the last interspace being .9 mm wide, and then they end abruptly. The interspaces in the banded region are also decidedly darker (light brown) than in the bandless region. In the second specimen (figure 22), from the same locality, which is 46 mm long, 9.4 mm wide at the wider end, and 5 mm at the narrower one, thirteen brown longitudinal bands can be seen on one half, while the other is entirely free from them. These lines, corresponding to the smaller size of the specimen, are but .3 mm wide at the thicker end and separated by interspaces .5 mm wide.

Fig. 21

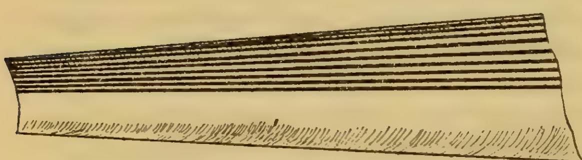

Fig. 22

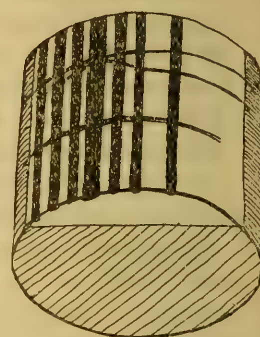

Fig. 23

Fig. 24

Fig. 25

Figs. 21–25 Geisonoceras tenuitextum (Hall). Figs. 21 and 22 Lateral views of specimens (fig. 21 natural size, fig. 22x2), showing color bands on upper side. Fig. 23. Portion of specimen, showing the black mud filling shaded. x2. Fig. 24 Dorsal view of specimen, natural size. Fig. 25 Section of color-bands.

In the third specimen, from Middleville, seventeen color bands are counted on one side, while there are none on the other. These bands are 1 mm wide, where the conch is 19 mm wide, and separated by interspaces, .5 mm wide. The color of the bands is light brown at the narrower end, where the conch is filled with crystallized secondary limestone, and black in the other portion where the conch is filled with the original black calcareous mud, forming the matrix. The fourth specimen shows only the banded side where ten color bands can be discerned.

These four specimens allow a number of observations, which bear partly on the nature of the color bands and partly on the habits of the creatures that made the shells.

The color bands were probably originally brown, as they appear now in three of the specimens. They are preserved only in that color where the conch remained free for a time from the dark mud that embedded the shells and became later filled by secondary white calcite. Thus in the first specimen, only a segment (the uppermost in the accidental position of the conch on the sea bottom) is filled with white calcite, the rest with black calcareous mud; the brown lines are seen on this segment, on the other part of the shell only as black smooth shadows. The second specimen is entirely filled with secondary calcite and retains the brown color lines in perfection. The third is only filled with crystallized white calcite in the narrower portion and the brown color lines are seen there. In the remainder they are dark brown to black.

The surface is, in all four specimens, provided with an extremely delicate surface sculpture, consisting of intersecting, nearly equal, transverse and longitudinal lines. These lines are so fine that they are only visible under a strong lens and about twenty are counted in 1 mm.

Not wishing to risk any of the specimens on account of the brittle nature of the crystallized calcite filling, we have not made any thin sections. On the natural section of the first specimen the brown band can be seen to extend about .1 mm into the interior of the shell as a dark-brown body, that thins toward the edges and extends to the surface. When weathering sets in, the lighter intervals between the colored bands begin to be dissolved first, the darker bands probably being protected by the insolubility of the pigment distributed there through the shell-substance. There result then the fluted forms which have been made the types of Orthoceras strigatum by Hall.

It is quite probable that this dark pigment belongs to the group of the melanin pigments which, according to Oppenheim (1918, p. 390), cause the dark coloring of numerous mollusk shells and being not dissolved by water, alcohol, ether and resisting even rather strong acids are little destructible. It is this utter insolubility in water which has secured for these melanin pigments the possibility of being preserved even through long geologic periods. Chitinous or conchiolinous substances, with which some have compared these pigments, would have been destroyed long ago. Especially in the present case, where the etching of the shell has been able to destroy only the lighter bands, it would seem that melanin pigments that are characterized by their resistance to acids, must be present.

The greater resistance of the color bands to solution and weathering has, as stated before, been also observed by Foerste. The fact that also in all cases of color banding observed by Foerste, this banding consisted of various tints of brown, suggests that all these color bands consisted of melanin, perhaps in association with iron (see Oppenheim, op. cit. p. 391). Em. Kayser's experiments in the Devonian brachiopod Rhynchonella pugnus indicate that also there a melaninlike pigment in chemical combination with iron is in evidence.

The new and important feature in the Trenton limestone specimens before us is the fact that the color bands are present on one side of the conch only, the other side having been entirely white. We see in this phenomenon direct evidence that the species in question, Geisonoceras tenuitextum, was given either to crawling upon the bottom of the sea, or to swimming in a horizontal position; either of which habits would develop a differential coloring on the dorsal and ventral sides, the former assuming a darker, the latter a lighter color. It seems improbable that the long and straight cones could have been carried horizontally in swimming, especially as these cephalopods must be assumed to have, like all their recent descendants, swum backward by the expulsion of water from the forwardly directed funnel. The often delicate shells could not have stood the shock of frequent impacts incidental to such mode of propulsion, and the prevailing preservation of the acute apex of the conchs militates against the view that such impacts could actually have occurred at frequent intervals. It is therefore more probable that the conchs, buoyed up by gas in the air chambers, were lightly dragged over the soft mud of the bottom, by the probably sluggish animals.

There are several other observations that support this conclusion. The most important is that the conchs on closer inspection turn out not to be regular cones, but to be slightly curved so that the side with color bands (dorsal side) is slightly convex, while the other is straight or even a little concave. This feature, distinctly observable by holding a ruler against any part of the dorsal or ventral side, is too regular to be due to *postmortem* compression or fracturing.

In the cross-sections of the conchs, both the dorsal and ventral sides appear a little flatter or less curved than the lateral sides. This, however, may be due to later compression.

Another observation that to us seems to indicate a crawling habit of this species has been made in specimens found in the Utica shale at Holland Patent. These specimens are overgrown with a delicate creeping bryozoan, Spatiopora lineata compacta nov. The zoaria of this bryozoan begin to grow near the apex and then regrow forward toward the aperture and on one side of the conch only. They would, of course, have also grown on one side only, if they had spread over the conch while, after the death of the creature, it was resting on and partly imbedded in the bottom mud. It is, then, inexplicable why they should have grown forward as a rule, upon the conchs; a fact that clearly suggests that they attached themselves to the living and still growing shells and grew with the latter. In that case, the fact that the bryozoan shunned the underside would also indicate that this was a true ventral side in the movements of the animals, and that these latter were upon the bottom.

Dr Rudolf Richter, in Frankfort a/M who has lately (1919) published an excellent study of the coloring of fossil brachiopods has upon my informing him of my find, kindly pointed out to me (in letter of May 14, 1920) some questions that were raised in a discussion of my observation by his colleagues and that are liable to be raised also by others and therefore may be answered here. These are:

1 Is the siphuncle somewhat excentric in that species; and if so, is the colored part of the shell oriented toward this excentricity of the sipuncle? The siphuncle is visible only at the narrow end of the second specimen and there is central in position.

2 Can the loss of color on the single shell not have come about *postmortem?* And then on the exposed side only, which was the upper at the entombment of the shell, while the side lying in the mud favored the preservation of the colors as much as in many German ceratites the longer preservation of the conch on the underside (cf. Phillippi und Riedel: Beitr. z. Pal. u. Strat. d. Ceratiten; Jahrb. Preuss. geol. Landesanstalt 1916, Bd. 37, Teil 1, Heft. 1); or like the mummy of Trachodon has preserved its skin only on the (presumed) underside?

Dr Richter adds in his letter that my observation of the wider spacing of the bands toward the lateral sides indicates a primary differentiation in the coloring of both sides of the conch. Also the fact that all three specimens which show both sides equally exhibit the banded upper and the white underside speaks for an actual color differentiation. Still more so does the fact that in specimens 1 and 2 the fine surface sculpture is equally well preserved on both the upper and under sides, thereby refuting the possibility of a stronger weathering of the uncolored side by temporary *postmortem* exposure. In specimen 3, where weathering and etching of the white intervals between the color bands has set in, both these and the underside lack the fine surface sculpture through secondary processes. Specimen 1 shows directly by the narrow segment (see text figure 23) with secondary crystallized calcite filling, which side happened to be the uppermost during entombment. This side which alone preserves the original brown color tint of the color bands belongs half to the dorsal and half to the ventral side. This shell came hence to rest on its lateral side during the entombment and it is the upper or exposed side that preserves the color banding most completely.

3 Would not the shell when ground near the oldest and most sensitive point, the apex, show traces of wear? The specimens with color banding at present available do not retain the apex. Specimen 2, which retains the youngest portion of these shells, is fractured still 45 mm from the apex. At the point of fracture, however, where it is but 5 mm wide, it retains the fine surface sculpture on all sides in the most perfect manner.

We thus see that the further facts brought out by the questions raised, rather help to corroborate the conclusion of the primary differentiation of the color banding on the ventral and dorsal sides of Geisonoceras tenuistriatum.

It is quite probable that also other species of Orthoceras with color banding possessed this only on one side. This is, at least, suggested by the specimen of Orthoceras trusitum Clarke and Ruedemann, from the Guelph limestone at Rochester and now in the New York State Museum, mentioned op. cit. by Doctor Foerste. In this the extremely narrow and crowded brown lines (nine to ten in a width of 3 mm) are also seen only on one side. They are, however, also there preserved only in certain patches and thus might well have been destroyed on the remaining parts of the surface. The same is true in regard to the other specimens among Clarke & Ruedemann's types which exhibit traces of color bands. Of these that of plate 13, figure 9, retains the fluting resulting from the weathering of the interspaces of the color bands, as far as the brittle specimen could be worked out, also only on one side. The type of the specimen of plate 12, figure 4, has on account of the longitudinal color lines been referred to Kionoceras darwini (Billings) by the authors, but since these lines are also but brown color lines and the shell is smooth, it should more properly be identified with Orthoceras trusitum. Also this specimen seems to possess the brown color bands on one side only.

The zigzag markings of the Bohemian species of Cyrtoceras mentioned above as well as the beautifully scalloped and wavy color bands which Barrande has so well figured of Crytoceras parvulum (pl. 481, figs. 1–15), C. zebra (ibid. figs. 16–20); C. cyathus (ibid. figs. 21–24), C. parvulum (pl. 504, figs. 1–45) etc. pass entirely around the shell. These transverse color bands thereby contrast with the longitudinal color markings of Orthoceras here described.

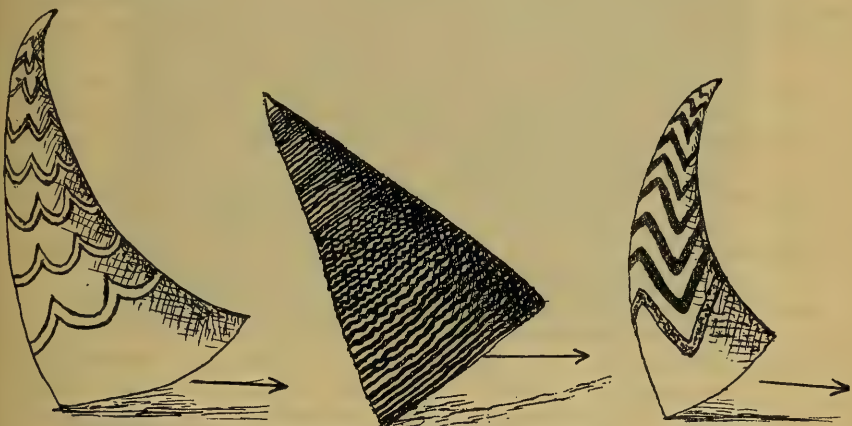

Fig. 26 Fig. 27 Fig. 28

Fig. 26 Cyrtoceras Zebra Barrande; fig. 27 C. parvulum Barr; fig 28 C. decurio Barr. (All after Barrande)

Likewise, do all the species of Cyrtoceras here cited, strongly contrast, by their breviconic and curved shells with wide open apertures with the long, slender, fairly orthoceraconic shells with longitudinal markings.

It is quite obvious that both color markings and form of conch are in both groups of shells in perfect harmony with their mode of life, in Orthoceras with a crawling habit, in which the conch is dragged behind; in the breviconic species of Cyrtoceras with a crawling habit in which the shell is carried obliquely or fairly upright, and as suggested by the position of the hyponomic sinus on the convex side, with the apex pointing forward.

The differentiation between dorsal and ventral color marking is lost in the latter forms, both sides being equally exposed to light and sight.

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5 A new Eurypterid from the Devonian of New York

The Devonian of New York has thus far afforded but extremely scanty remains of eurypterids, and these are referable to two species, apparently all of the genus Stylonurus. These are the Portage form *Stylonurus (?) wrightianus* (Dawson), represented only by a leg joint, and the Catskill form *Stylonurus (Ctenopterus) excelsior* Hall. If we add to this the other Catskill species *S. beecheri* (Hall), from Warren, Pa., known only from an abdomen and leg and the *Pterygotus atlanticus* Clarke and Ruedemann, from the Devonian of New Brunswick, based on some fragments of appendages, the list of the eurypterid remains in our Devonian is completed (excluding two very doubtful eurypterids from New Brunswick). Any find of eurypterid remains is therefore of great interest and worth recording.

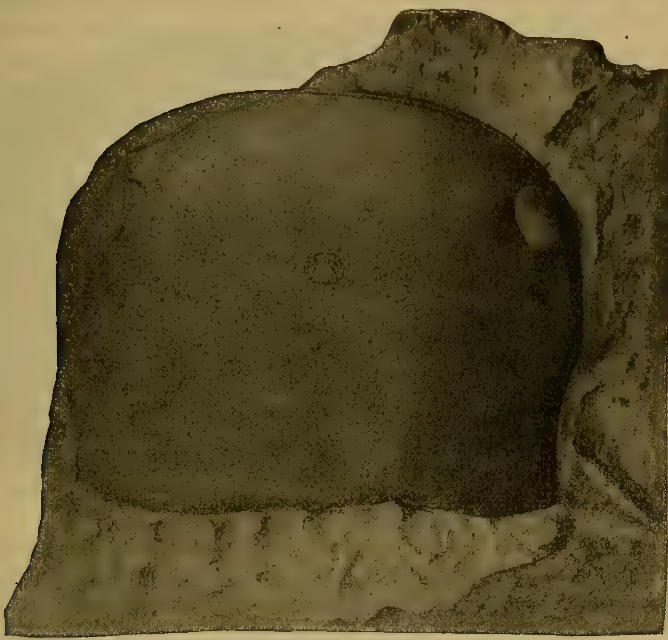

Fig. 29

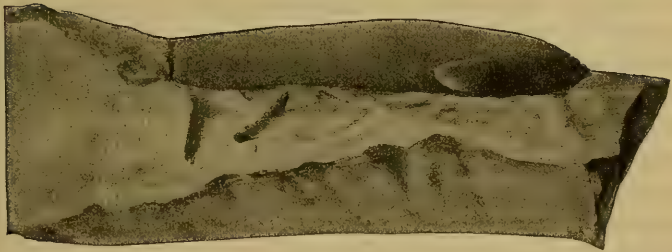

Fig. 30

Figs. 29, 30 Pterygotus inexpectans nov. Dorsal and lateral views of type. Natural size.

The subject of this note is a carapace of a Pterygotus found by the writer while collecting fern-trees in the Oneonta beds at Gilboa, N. Y., in association with Messrs C. A. Hartnagel and H. P. Woodward.

Pterygotus inexpectans nov.

Description. Cephalothorax trapezoidal in general outline, about one-ninth wider than long; the lateral margins slightly sigmoidal, being concave in the posterior, and convex in the anterior half, producing a slightly forwardly expanding shape of the carapace. Anterior margin well rounded, and posterior margin nearly transverse, slightly bent forward at the subrectangular postero-lateral angles. The surface seems to have been flat in the posterior half and gently convex in the anterior, with a fairly abrupt decline at the frontal margin. The lateral eyes are very prominent, but relatively small (a little more than one-fifth the length of the carapace), subelliptic in outline and situated in the antero-lateral corner of the carapace. The ocelli are large and distinct, and situated on a line connecting the posterior extremities of the compound or lateral eyes; or about two-fifths of the length of the carapace from the anterior margin. The marginal thickening is well developed, about 1 mm wide. The surface shows traces of low tuberculation.

Measurements. Greatest width (behind compound eyes) 66 mm; basal width 62 mm; length 53 mm; greatest height 8 mm. Length of compound eyes 10.5 mm; width of same 6 mm.

Horizon and locality. Upper tree-fern beds in Oneonta sandstone at Gilboa, Schoharie county, N. Y.

Remarks. This is the first Pterygotus found in the Devonian of New York. Compared with its American Silurian congeners, especially P. buffaloensis and macrophthalmus, it is distinguished by the relatively small size of the compound eyes and the sigmoidal curve of the lateral margins, or the forward expansion of the carapace; features in which it shows a certain approach to the Old Red sandstone forms of Scotland, and particularly to the remarkable Slimonia acuminata, which not only possesses like small, but prominent lateral eyes, but also a slight lateral expansion of the carapace in the anterior portion and a like strongly developed thickening of the margin.

Both the discovery of the carapace and leg parts of the gigantic Stylonurus excelsior near Andes in the Catskill beds, and the finding of this Pterygotus which, judging from the carapace in hand, also reached a size of a foot and a half, in the underlying Oneonta beds, suggest that some day there may be obtained in the American equivalent of the British Old Red sandstone, in the Catskills of New York, an eurypterid fauna as striking and important as that made known by Salter and Woodward from Great Britain.

Note. Since writing the above two more remains of eurypterids have been obtained in the Devonian plant-beds; one the cephalothorax reproduced in text figure 31, and the other the small specimen seen in text figure 32.

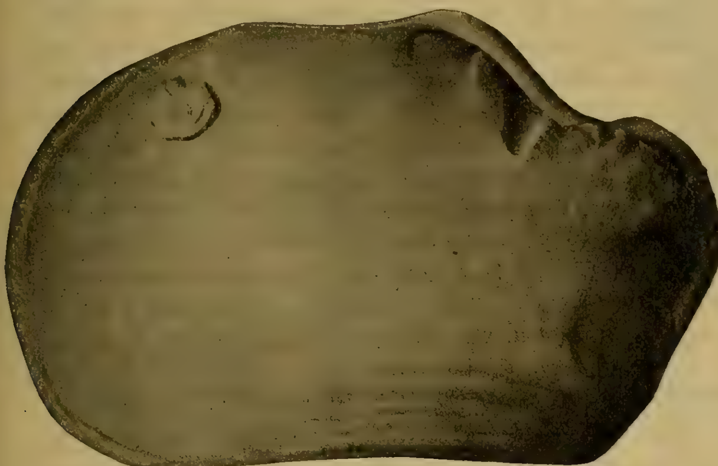

Fig. 31

Fig. 32

Figs. 31, 32 Pterygotus cf. inexpectans nov. Natural size.

The larger specimen was collected in the Oneonta sandstone at the Manorkill near Gilboa, below the horizon of the tree trunks. It is preserved in a sandstone that contains numerous brachiopod shells, mostly Spirifers, of the disjunctus type, and a new Hydnoceras. The smaller is embedded in a mud shale full of plant remains and recorded as having been collected in the Catskill beds near Walton, N. Y.

The cephalothorax apparently belongs also to the species here described, but is strongly compressed from the front backward, as is indicated by the folds paralleling the posterior margin and by the bulging out of the cheeks, especially the left one. A restoration of the shield to its original form would furnish an outline fairly corresponding to that of the type specimen. The compound eye was preserved on the left side in the antero-lateral corner, but partly lost in working out the specimen. The surface is slightly weathered and rough on the right side which had been exposed for some time and fairly smooth on the left which was protected in the matrix and chiseled out. The specimen is mainly interesting on account of its larger size and its association with a distinctly marine fauna.

The posterior portion of a smooth cephalothorax that may very well have belonged to the same species was also found in the plant beds that have afforded the smaller specimen. This small individual may also belong to the same species. At least the outline of the cephalothorax and of the postabdomen, as well as the submarginal position of the supposed compound eye, suggest its reference to Pterygotus, although the specimen is not sufficiently perfect to give conclusive evidence as to either its generic relation or relative age. The cephalothorax is narrower than in the adult age, but possibly so to some degree by lateral compression. The preabdomen retains only one or two segments, the first of which is pushed under the cephalothorax, and the postabdomen has been pushed forward into the preabdomen, giving the body an altogether too short outline. Traces of relatively weak and narrow swimming legs, such as are possessed by Pterygotus are seen close to the sides of the body.

6 Preservation of Alimentary Canal in an Eurypterid

A small series of eurypterids from the Silurian waterlime at Kokomo, Ind., bought some years ago from Ward's Natural Science Establishment, contains a specimen of Eusarcus newlini Claypole, that is worth noting for two reasons; first, it is a younger individual than has hitherto been observed and exhibits certain adolescent features; and second, it retains the alimentary canal; to the writer's knowledge, not before observed, or described, at least, in any eurypterid.

The specimen is but 142 mm long, or one-fourth the size of the large specimen figured by Clarke and Ruedemann (*The Eurypterida of New York,* 1912, on pl. 39). In its relative dimensions it corroborates the view expressed before (ibid., p. 252) that the mature individuals had a more robust and less agile appearance; for this young individual is distinguished from the supposedly mature form by a relatively more slender body, a more elongate carapace, less broadly expanded preabdomen and relatively longer postabdomen. The legs are distinctly more slender, though not relatively longer. The eyes which are placed terminally in front, are more prominent than in the later stages though not any more relatively larger.

The alimentary canal is traceable through the greater part of its length. It is seen from the dorsal side, beginning in the middle of the carapace with an expanded portion 8 mm long and 5 mm wide and extends thither as a perfectly straight tube, with a nearly uniform width of 3.5 mm to within 3 mm of the posterior edge of the last postabdominal segment, where it abruptly disappears.

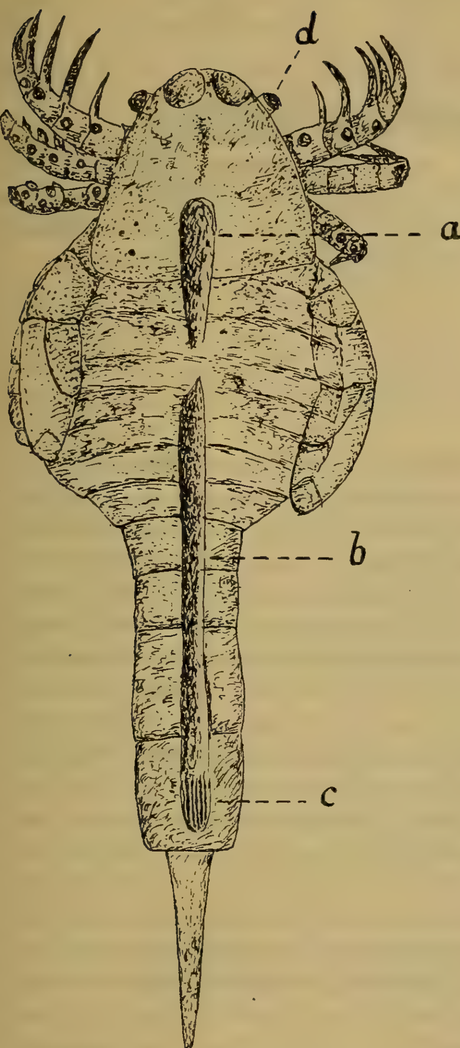

Fig. 33

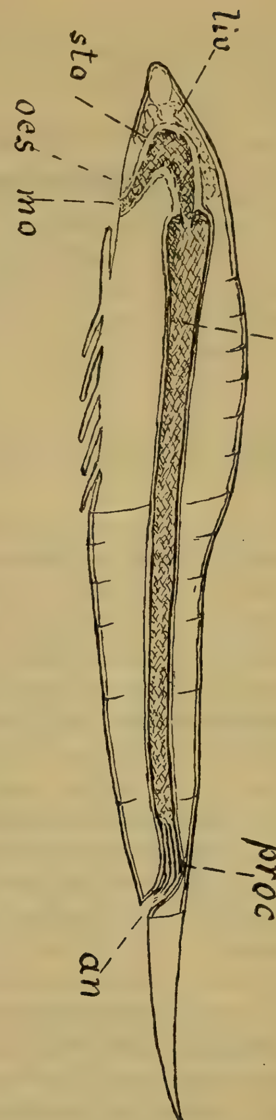

Fig. 34

Figs. 33, 34 E u s a r c u s n e w l i n i Claypole. Fig. 33 Specimen retaining alimentary canal: a expanded anterior portion of mesenteron, b mesenteron, c proctodaeum or rectum. Natural size. Fig. 34 Diagrammatic view of median longitudinal section showing alimentary canal. *Mo.* mouth, *oes.* oesophagus, *sto* stomach, *liv* liver, *in* intestine, *proc* proctodaeum, *an* an~~n~~us.

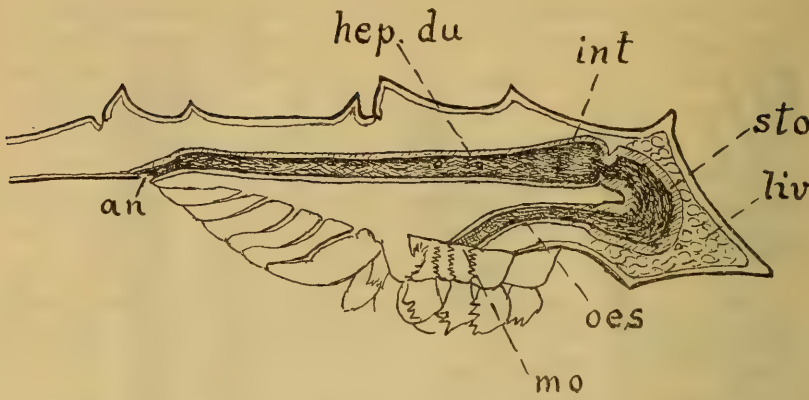

Fig. 35 Diagrammatic view of median longitudinal section of *Limulus*. Lettering as above. (After Parker and Haswell.)

A comparison of this intestine with that of Limulus (see text figure 35) shows that the two are identical in shape and position; the exposed part of that of Eusarcus newlini beginning with the slightly expanded anterior portion of the mesenteron behind the stomach (proventriculus). The latter was, undoubtedly, as in Limulus, situated at the anterior extremity of the cephalothorax and extended downward, being more or less bent upon itself, leading anteriorly into a suctorial pharynx and the oesophagus, and being surrounded by a large gland, the so-called "liver."

The intestine or mesenteron itself was a straight tube, relatively much longer than in the more compact Limulus.

The posterior portion exhibits distinct longitudinal folds and possessed thus a like structure as the proctodaeum or rectum of Limulus.[4]

It appears that the proctodaeum was as in other eurypterids, first bent upward, producing in some, as in Pterygotus, a crest by impinging against the dorsal side of the ultimate segment, and then sharply downward; the anus, which was on the ventral side, not being exposed in the specimen.

The preservation of the intestine is proof that the specimen was not originally a molted skin, but a whole individual that became entombed at the bottom of the sea; and the excellent preservation and undisturbed position of the appendages indicate that the creature

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[4] See the elaborate "Studies of Limulus" by Patten and Redenbaugh. (Journal of Morphology, v. 60, 1900.)

had lived where it was buried, in the Silurian sea which deposited the Kokomo limestone at approximately Bertie time, and was hardly carried any great distance out to sea, as some would have us believe.

7 Note on Caryocaris Salter

The genus Caryocaris was erected by Salter (1863, p. 135) for a small crustacean from the Skiddaw slate series of Wales. His monotype C. wrightii is described as follows: "A long, pod-shaped, bivalved carapace (with distinct hinge-pits), rounded anteriorly, subtruncate behind, and with the back and front sub-parallel. The surface is smooth, or with only oblique wrinkles near the margins, but with no parallel lines of sculpture. Body? Telson and appendages?" The little crustacean is described with the Skiddaw graptolites and stated to occur "everywhere in the Skiddaw slate district."

In 1876 a second species was described by Hicks as C. marrii (1876, p. 138). This form, which is associated with the genotype, is said to be smaller, being both shorter and narrower.

The genus is noted again in the first part of the British Palaeozoic Phyllopods by Jones and Woodward (1888, p. 5), where in the table of the known genera of fossil Phyllocarida, it is placed near Ceratiocaris and the carapace characterized as "podlike; elongate, narrow, smooth," and the genus as occurring in the Arenig and Lingula flags.

In the second part of this important monograph, both C. wrightii and C. marrii are elaborately described and figured, and a third form, which had been made known by M'Coy as Hymenocaris salteri from the graptolite shales of Australia is also, with doubt, referred to Caryocaris, as Salter had done already in 1863 when he saw the specimen.

Of all these species only the carapaces are described. These alone were known to Salter who, however, in a restoration suggested "a strong, tapering telson (or last body-segment), carrying a sharply lanceolate style and stylet" (see text figure 36). Professor Marr found in association with Caryocaris some small slender spines or pointed styles which are longer than Salter's ideal figure (Jones and Woodward, p. 89) and Professor Malaise loaned the authors of the monograph a specimen from the graptolite shale at Gemboux, Belgium, that shows "three definite sharp daggerlike stylets as the cercopods of this genus" (see text figure 37).

Fig. 36

Fig. 37

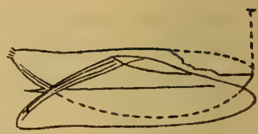

Fig. 38

Fig. 39

Fig. 40

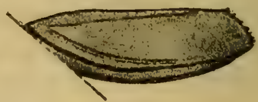

Fig. 41

Fig. 42

Fig. 43

Fig. 44

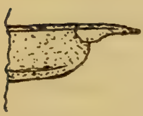

Fig. 45

Fig. 46

Fig. 47

Fig. 48

Fig. 49

Fig. 50

Fig. 51

Fig. 36 Salter's figure of Caryocaris wrightii. Fig. 37 Specimen figured by Jones and Woodward. Fig. 38 C. curvilatus Gurley (Gurley's figure). Fig. 39 Gurley's figure of C. wrightii. Figs. 40–44 Carapaces and telsons of C. curvilatus (Ruedemann's figures, 1908). Figs. 45–51 New figures of C. curvilatus. Fig. 45 Anterior carapace with rostrum, x3. Fig. 46 Carapace with abdomen. Nat. size. Fig. 47 Posterior fringe of carapace, x3. Figs. 48, 49 Abdomina, x3. Fig. 50 Telson of large specimen, x3. Fig. 51 Restoration in natural size.

In 1896 (p. 85) Gurley described three species of Caryocaris from America, namely, C. wrightii, C. oblongus and C. curvilatus, the first from the Beekmantown shale in Nevada, the second from the same shale in Quebec, and the third from both regions. He referred, however, the genus to the graptolites, from its supposed resemblance to Dawsonia, claiming (ibid., p. 86) that Lapworth agreed with him in this view. Gurley held that what hitherto had been described as Caryocaris were only appendages, and that the complete body consists of "two symmetrically paired lateral appendages attached to the distal end of a single median proximal portion on which thecae could perhaps be traced" (see text figure 39). This view was rejected in a brief note by Wiltshire, Woodward and Jones the year after it had been advanced (1897, p. 4).

In the first volume of the Graptolites of New York, (1904, p. 737) the present writer has doubtfully referred a form from the Deep kill shale of New York to Caryocaris curvilatus but having only the podlike bodies before him he did not care to select between the conflicting opinions.

In the preparation of the second volume, the writer had an opportunity of studying Gurley's type material from the Piñon range in Nevada and it was then recognized that this material contained partial abdomina with the telson consisting of a style and two flanking cercopods, and that these abdomina had been construed by Gurley into winged graptolite rhabdosomes (see Ruedemann, 1908, p. 486). It may be mentioned here that on inspection of the preservation of the material, the similarity of the substance of both groups of fossils, and the frayed character of the margins of many specimens, due to the "plaiting" or imperfect cleavage of the shale and suggestive of graptolite thecae, readily enough explains the origin of Gurley's misconception about their nature.

While undoubtedly a crustacean, Caryocaris still remained an imperfectly known genus; as is indicated by Zittel's definition, retained in the last edition of Zittel–Eastman's textbook (1913, p. 751) which reads: "*Caryocaris, Salter.* Carapace smooth, subacute in front, thick. Abdomen unknown; caudal plate with three spines. Cambrian; Wales."

In a collection of Lower Ordovician graptolites from the Alaska-Yukon boundary sent to the writer by L. D. Burling of the Geological Survey of Canada for identification, a small number of specimens of Caryocaris were noted, one of which retains the abdomen in place. This fact as well as the presence of other characters hitherto unknown have suggested this note, the material having been kindly presented to the New York State Museum by Mr Burling.

The shape of most of the individuals in both the American and British graptolite shales being more or less modified by pressure, it is somewhat hazardous to base specific differences on the outline of the carapace. The British authors, however, have separated a very narrow form as C. marrii from the broader wrightii. Of the three species distinguished by Gurley among the American forms, C. wrightii may be rejected on the ground that the author based this identification on telsons and a misconception of the structure; his C. oblongus, a Point Levis form, and said to be distinguished from the others by its "regularly oblong shape" is too imperfectly known to concern us here. His C. curvilatus, however, from the Beekmantown graptolite shale of Summit, Nevada, as based on his first figure (see text figure 38) appears to comprise the form before us from the Alaska-Yukon boundary. At any rate, the latter is not sufficiently different either in age or outline to warrant distinction in this place.

One of the bivalved carapaces (see text figure 46), 22 mm long, though not perfect in front, retains a short, rapidly tapering abdomen 6.5 mm long in which five segments can be distinguished, beyond the posterior extremity of the carapace, not counting the last segment which may represent the telson (the specimen is not complete at this end either). Another detached abdomen (see text figure 49) exhibits five segments and a fragment of a sixth, besides the telson spine, so that it may be said with reasonable security that the abdomen of Caryocaris consisted of six or more segments. The caudal appendages (see text figure 50) consist of a broadly acute style (telson) that is flanked by two somewhat leaflike expanded or lanceolate stylets or cercopods. The inner edge of these were seen in the Nevada material (see text figure 44) to be provided with fine setae.

The carapace was considered by Salter as being broader posteriorly, Jones and Woodward (op. cit., p. 90) preferred, however, "to regard the broader and prow-shaped end as the front." Our material fully supports their contention.

The posterior margin appears often provided with a fine ciliated fringe. Jones and Woodward observed this, but owing to the "plaiting" or imperfect cleavage of the compressed flagstone attributed this feature to the incidents of preservation, stating that owing to this cleavage, "occasionally, when they [the valves] lie parallel with the superinduced grain of the schist, their ends are frayed out or 'plaited' into a mere fringe." The writer (op. cit., 1908, p. 488) following suite, also attributed the "row of cilialike processes" observed by both Gurley and himself at the posterior margin of the carapaces of C. curvilatus (see text figure 47) to this "plaiting." The Alaska–Yukon material, however, which is not obscured by an imperfect cleavage leaves no doubt that the posterior margin of the carapace was indeed furnished with a fine comb of uniform bristles or teeth corresponding to the "fringe" observed in certain species of Ceratiocaris, as p. e. C. (Limnocaris) salina Ruedemann (N. Y. State Museum Bul. 189, pl. 33, fig. 4, 5).

Gurley's type specimen of C. curvilatus exhibits (see text figure 38) a straight line projecting between the two partly overlapping valves, that remained unexplained by Gurley, but was suggested by the writer (op. cit., 1908, p. 488, footnote) to be possibly of the nature of a rostrum. The specimen, here reproduced in text figure 45 exhibits the true rostrum. It shows a distinct plate in position, that is very sharply acute in front and rounded ovate posteriorly and that can not be otherwise considered but as a rostrum. The straight thick line along the dorsal margin may be only a reinforced edge rather than a median plate.

No distinct eye-tubercles could be made out in the material at our disposal.

It may finally be noted that Zittel's Handbuch and Zittel–Eastman's textbook cite Caryocaris as a Cambrian genus according to the former correlation of the Arenig flags. The Skiddaw graptolite shales in Great Britain are, however, now known to be of Lower Ordovician age and to correspond to the graptolite beds in Nevada, Levis at Quebec and the Alaska–Yukon boundary which have afforded the American specimens of Caryocaris. It is, hence, safe to define Caryocaris properly as a Lower Ordovician or Canadian genus, instead of a Cambrian one; as indeed has already been done by Bassler in his invaluable Bibliographic Index.

The form of the abdomen, telson and rostrum here described, leave no doubt that Caryocaris is closely related and very similar to the genus Ceratiocaris, that becomes so prominent in the later Ordovician and Silurian periods. It still differs from the latter in the shape of the carapace which is broader anteriorly and in the absence of any linear surface sculpture.

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8 Fauna of the Dolgeville Beds

Professor Cushing (see Miller, 1909, p. 21) has designated as Dolgeville shales the passage beds between the Trenton limestone and Utica shale in the Dolgeville region, 25 miles east of Utica. It has been pointed out by the writer (1912, p. 27, 28) that these beds, and we may add, the directly overlying black shale as far as the fall below Dolgeville, contain the fauna of the upper Canajoharie shale. There was no faunal list of the Dolgeville shale published at the time. Having had occasion in the meanwhile, in connection with the study of the Utica, to prepare a list of the Dolgeville fauna, we wish to embrace this opportunity to put the same on record, partly because it contains some very interesting elements that were not noticed in the other outcrops of Canajoharie shale, and partly because it represents the westernmost occurrence of the Canajoharie in New York.

There were obtained, by the writer, in these beds:

Teganium rauffi *Ruedemann* r
Climacograptus spiniferus *Ruedemann* r
C. typicalis *Hall*
Glossograptus quadrimucronatus postremus *Ruedemann* c
Lasiograptus (Thysanograptus) eucharis *Hall* cc
Chaunograptus gemmatus *Ruedemann* rr
Paleschara *sp.* r
Lingula curta *Hall* c
L. riciniformis *Hall* c
Leptobolus insignis *Hall* cc

Schizocrania filosa *Hall* r
Dalmanella *cf.* rogata *Sardeson* r
Conularia papillata *Hall* rr
C. gracilis *Hall*
Serpulites angustifolius (*Hall*) c
S. gracilis *Ruedemann*
Liospira cf. subtilistriata (*Hall*) r
Triarthrus becki *Green* c
Calymmene senaria *Conrad* c
Isotelus gigas *Dekay* r
Ulrichia bivertex (*Ulrich*) c
Primitiella unicornis (*Ulrich*) c
Primitia *sp.*
Aparchites minutissimus (*Hall*) c

While there are already present a considerable number of Utica forms, the fauna as a whole differs in aspect from the later lower Utica in the presence of such Canajoharie species as Climacograptus spiniferus, Ulrichia bivertex and Primitiella unicornis. In Conularia papillata, C. gracilis, Serpulites gracilis, Chaunograptus gemmatus, the horizon affords peculiar types possibly restricted to it.

9 Additions to the Snake Hill and Canajoharie Faunas

The Snake Hill shale of the Hudson River valley, of lower and middle Trenton age, has afforded a large and peculiar fauna, of which eighty-three species have been listed thus far (Ruedemann, 1912, p. 62, 63), many of them new to science. It seems worth while to record in this place additions to this fauna from the temporary exposures at North Albany and at Watervliet, a few miles north of Albany.

1 Dystactospongia radicosa nov.

Description. Sponge of medium size elongate, probably cylindrical and originally of massive structure. Paragasters small, widely apart on surface, surrounded by radiating and anostomosing furrows. The latter contain scattered depressions, apparently former apertures (postica), that in some places become so closely crowded as to constitute the furrows. The lower (?) or supposedly basal portion of the sponge shows concentric wrinkles, suggestive of the presence of an epithecal layer. Skeletal elements mostly destroyed, through solution and compression; those noticed apparently of a nature that would indicate a composition of tetraxons similarly as is found in aulucopoid Lithistidae.

Measurements. Length of type-specimen 73 mm; width 25 mm; diameter of radial systems of furrows 15 mm; width of paragasters 1 mm.

Horizon and locality. Black calcareous shale at Rockwell's, Isle La Motte, Vermont; of Trenton age and most probably referable to the Canajoharie shale.

Fig. 52

Fig. 52 Dystactospongia radicosa nov. Natural size.

Remarks. The type specimen was collected by the late Prof. H. M. Seeley of Middleburg, Vt., and sent by him to the United States National Museum (no. 15242). The single striking feature of the imperfect fossil is the groups of radiating surface canals (aporrhysa), that surround the paragasters, of which three may be counted in our specimen. The latter are, owing to the imperfection of the material through flattening of the specimen much obscured. The section of the specimen, seen along a fracture, is very flat lenticular, without a trace of a median line or layer, that might have resulted from the presence of a general cloaca, making the cylinder a hollow one.

We have referred this species to the genus Dystactospongia Miller, because it has in common with that genus, as represented by the genotype D. insolens, the system of paragasters with radiating furrows. We are well aware of the fact that the skeletal system of that genus is still unknown and that for that reason it has but little standing in modern spongiology and, moreover, may finally turn out to have an entirely different skeletal structure than our form. Nevertheless, as an American author on sponges has aptly remarked, even though the structure of these sponges is as yet conjectural, they need names before all so that they may be noticed and handled by collectors and in the literature. We may leave then to time the production of better specimens, and the elaboration of their skeletal structure.

2 Trematis punctostriata Hall. var. minor nov.

This well-characterized species, hitherto known only from the middle Trenton (Hermitage) of Tennessee and Kentucky has been found in numerous, though mostly fragmentary and small, speci-

Fig. 53

Fig. 54

Fig. 55

Fig. 56

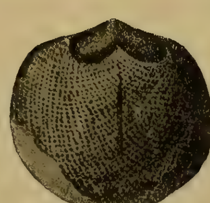

Fig. 57

Figs. 53–56 Trematis punctostostriata Hall var. minor nov. Fig. 53 Type x3. Fig. 54 Cotype x2. Fig. 55 Enlargement of sculpture. Fig. 56 Pedicle-valve, x3. Fig. 57 Trematis terminalis (Emmons) x2.

mens in the Snake Hill shale. These exhibit the characteristic sculpture of the species, consisting of relatively distant pits placed in radiating grooves. The largest specimens, attaining a length and width of about 8 mm, agree in outline with the typical material from Clifton, Tenn., while the smaller individuals are narrower and with more prominent beaks, suggesting in this regard the later T. umbonata Ulrich. Considering this difference and that in size, it is seen that the Snake Hill form, may properly be considered as a smaller variety. It is evident that the whole Snake Hill fauna is largely a microfauna due to the unfavorable shale facies, and that one could recognize a considerable number of forms as small varieties of species occurring in larger individuals in the limestone facies of the Trenton.

Trematis punctostriata was originally described by Hall in the 23d Report, New York State Cabinet of Natural History, 1873, and has been fully figured by Hall and Clarke in the Palaeontology of New York, volume VIII, plate IVG. It has more recently been discussed by Foerste (1910, p. 37) who describes the shell as large, attaining a width of 30 mm; being nearly circular in outline; the width a little greater than the length. The brachial valve is, in our specimens as in the typical material, " moderately convex, the convexity increasing toward the beak." The radiating rows of pits are closer together, and the pits larger, in the anterior half of the shell, according to Foerste, eight to eleven rows occupying a width of 2 millimeters. We have counted eleven rows, on fragments, of the anterior portion, within the mentioned space. " Posteriorly, especially along the umbonal part of the shell, the radiating rows are more distant, and appear like narrow grooves crossing an otherwise comparatively flat surface." These grooves near the edges of the posterior portion are well seen in the figures here given of the variety minor.

3 Trematis terminalis (Emmons)

Another Trematis of the Snake Hill shale, north of Albany, deserving mention in this place, is T. terminalis Emmons. This form, formerly known only from the Trenton limestone in New York (Middleville, Trenton Falls, Watertown etc.) occurs in large individuals, attaining a length and width of 12 mm.

4 Triplecia nucleus (Hall)

We refer a small Triplecia from the Snake Hill shale at North Albany to this species because of its subcircular outline, small size of radial striae and the character of the fold, which is narrow, short and not produced anteriorly. T. nucleus is known from the middle Trenton at Middleville, N. Y., and the Rysedorph Hill conglomerate. Its occurrence in the Snake Hill shale is another link between that shale and the Trenton limestone.

Fig. 58

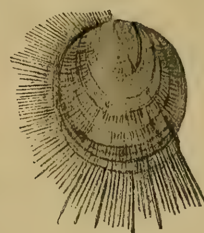

Fig. 59

Fig. 58 Triplecia nucleus (Hall), x2. Federal Signal Works, North Albany. Fig. 59 Schizambon albaniensis, nov. Holotype, x2.

5 Schizambon albaniensis nov.

Description. Shell of medium size, subelliptic in outline, about four-fifths as wide as long, widest in the middle, posterior end truncate with gently convex cardinal line. Foramen ovate in outline, situated about one-third of length of shell from beak. Surface furnished with coarse broad, smooth growth bands which are continued into long bristlelike spines which are straight and longest in the anterior region, toward the posterior region are curved slightly backward, reaching a second climax of length near the latero-cardinal angles, and continue as small spines along the cardinal line.

Measurements. Length of type-specimen 10.2 mm; greatest width 8.8 mm; length of cardinal margin 5 mm; length of anterior spines 3 mm.

Horizon and locality. Snake Hill beds at Watervliet near Albany (excavations for the shops of the Delaware and Hudson railroad) and Canajoharie shale at Rural cemetery at Albany.

Remarks. This species has before (Ruedemann, 1901, p. 529, 1912, p. 30, 63) been cited by the writer as Schizambon ? fissus var. canadensis Ami, which is now Schizambon canadensis, a species of the Gloucester shale. From this species our form as here figured from the Snake Hill beds differs in its outline, which is truncate posteriorly and subelliptic instead of ovate; and further in the direction of the spines in the posterior region which are curved, and continue along the cardinal line.

Winchell and Schuchert (1895, p. 361) have described as S ? dodgei a form from the Trenton limestone (Glens Falls limestone) at Sandy Hill, N. Y. This species, but little older than S. albaniensis, differs in being broader, more acute posteriorly and in possessing shorter and stouter spines.

Our material has not furnished any evidence as to the interior characters of the species. The foramen is large, situated relatively far forward (4 mm from posterior margin) and connected by a groove with the beak.

6 Tetranota bidorsata (Hall)

This species, originally described and figured by Hall (1847, p. 187) as Bucania bidorsata from the Lower Trenton at Middleville and Watertown is not uncommon in the Snake Hill shale at North Albany. The specimen figured has the lateral carinae so well developed, and has such a wide volution, that it suggests T. sexcarinata Ulrich, a western Stones River to Trenton form; other specimens of the Snake Hill shale appear, however, as good representatives of Hall's species. T. bidorsata is now known (Bassler 1916, p. 1271) to range from the Stones River into the Trenton and to occur from Nevada to New Jersey and Canada.

7 Kokenospira rara nov.

In describing Kokenia costalis, the monotype of the genus, Ulrich and Scofield (1897, p. 882) write: "We have seen but a single imperfect specimen of this species, and were it not that it belongs to a very interesting and easily recognized type, we would scarcely be justified in describing it."

The writer has to offer the same excuse of extreme biologic and paleogeographic interest attaching to the imperfect specimen before him, for it not only furnishes a new representative of the genus Kokenospira Bassler (=Kokenia Ulrich and Scofield, which name was preoccupied), but also suggests a northern paleogeographic connection for the isolated Snake Hill shale fauna of New York. The Snake Hill shale of the slate belt of eastern New York is of early Trenton age; so is the occurrence of K. costalis near Cannon Falls (Minnesota) in the Prosser limestone, and the further important discovery of a Kokenospira at Frobisher Bay, Baffin Land, by Schuchert (1900, p. 164). The genus is also represented in the Baltic region (K. esthona Koken) and has thus a distinctly subarctic distribution.

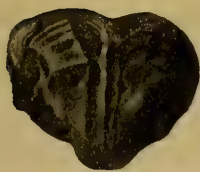

Fig. 60

Fig. 61

Fig. 60 Tetranota bidorsata (Hall). Nat. size. Fig. 61 Kokenospira rara nov. x2.

The specimen exhibits the following characters:

Description. Shell small, probably subglobular in form, 9 mm wide and 7.5 mm long, in vertically compressed condition; height not known; volutions broad enlarging gradually to the aperture; slit-band wide, smooth, slightly concave with filiform edges, the sides evenly and strongly convex to the umbilicus, which is too much compressed to show its nature. Aperture but slightly expanded apparently with but a shallow central emargination of the dorsal side. Surface on each side of slit-band with five (or more?) sharply elevated, outwardly curving revolving lines which alternate with finer ones that do not reach the aperture. Growth lines indistinct, except some very coarse lines paralleling the frontal margin.

From K. costalis our species is at once distinguished by the alternation of the revolving striae, and from K. esthona in the lesser prominence of the slit-band.

Schuchert states regarding the two Frobisher Bay specimens, which he identified with K. costalis, that they agree with the Minnesota form, of which there are two specimens in the National Museum, excepting the number of revolving lines. " Of these there are seven in the Minnesota specimens, while in the Arctic individuals there are from eleven to twelve, of which the fourth, sixth and eighth are the most prominent. The first, second, fourth, sixth and eighth revolving lines are continuous into the aperture, the others being interpolated on the last volution." This description leaves hardly any doubt that the Frobisher form is identical with ours, and further that the type thus marked by alternating striae should be distinguished from the Minnesota form with uniform lines.

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10 The Age of the Black Shales of the Lake Champlain Region

The black shales of the Champlain region form a continuous belt on the Vermont side of the lake, but appear only in a few small sporadic patches on the New York side. They form the top of the Ordovician series and are considered to this day as Utica shale (see Perkins, 1916, p. 208) for the good reason that they are black shales of the appearance of the Utica shale, rest upon Trenton limestone and while very barren, still contain in "Triarthrus becki" and "Diplograptus pristis," "Climacograptus bicornis," "Schizocrania filosa," "Orthoceras coraliferum" (see Perkins 1904, p. 106) species that would appear as fair evidence of Utica age.

The existence of a fine transitional series from the Trenton limestone to the Utica shale on the shore of Lake Champlain in the town of Panton, Vt., was pointed out to the writer by the late Dr Theodore White of Columbia University, and the locality visited in 1899. From the fossils then obtained, especially the presence of a Corynoides, the writer later (see Ruedemann, 1908, p. 37) inferred that the black shales intercalated in the top of the Trenton limestone series, represented low Utica and were of about the same age as the shale at the Rural cemetery at Albany, then also considered as early Utica. When this shale later (Ruedemann, 1912) was recognized to be of early Trenton age and placed with the Canajoharie shale, and it became further obvious that no Utica shale was developed as such in the Hudson valley and Utica beds there probably absent altogether, the question of the age of the so-called Utica shale of the Champlain region came up at once, and it has since been the conviction of Doctor Ulrich and the writer that there is no Utica shale in that region, but that the black shales, attaining such a great thickness in western Vermont, are older than Utica age.

The writer had in 1899 collected only from the transitional beds, but the Rev. E. W. Gould, then of Bristol, Vt., an enthusiastic student of geology, undertook in 1918, upon my suggestion, to collect from the entire shale section. He found two exposures of shale, one extending from Arnolds bay northward (and southward) until rather abruptly replaced by the heavy Trenton limestone, apparently by a fault. This limestone farther north changes gradually through about 50 to 100 feet of transition beds (limestone beds, about 2 feet thick with soft black shale between) into the black shale.

Mr. Gould and the writer visited the section in 1919, collecting from the top of the Trenton limestone, the transition beds and all parts of the overlying black shale; the latter, taking the covered intervals at the north end in account, reaches 400 feet or more in thickness.

The top of the Trenton limestone, just below the transition beds consists of gray crystalline limestone and contains:

Mesotrypa quebecensis *Ami*
Rafinesquina *sp.*
Plectambonites sericeus (*Sowerby*)
Dalmanella rogata (*Sardeson*)
Parastrophia hemiplicata (*Hall*)
Protozyga exigua (*Hall*)
Calymmene senaria *Conrad*
Isotelus *sp.* (fragments)
Ceraurus pleurexanthemus *Green*
Aparchites minutissimus (*Hall*)
Leperditia *sp.*

On top of the limestone cliff, the writer had before collected:

Streptelasma corniculum (*Hall*)
Dalmanella *cf.* rogata (*Sardeson*)
Liospira americana (*Billings*)
Spyroceras bilineatum (*Hall*)
Bythocypris cylindrica (*Hall*)
Primitia *sp.*

The limestone at the beginning of the transition series has afforded:

Mesotrypa quebecensis *Ami*
Plectambonites sericeus (*Sowerby*)
Dinorthis meedsi *W. & S.* (Large form) c

The intercalated shale contains near the base:

Climacograptus strictus *Ruedemann* (putillus *auct.*)
Climacograptus spiniferus *Ruedemann* r (bicornis *auct.*)
Mesotrypa quebecensis *Ami*
Dalmanella rogata *Sardeson* c
Rafinesquina *sp.*

Leptobolus insignis *Hall* r
Rhynchotrema increbescens (*Hall*)
Ctenodonta levata (*Hall*) r
Primitiella unicornis *Ulrich* cc
Ulrichia bivertex (*Ulrich*) cc
Cryptolithus tesselatus *Green*
Bathyurus *cf.* spiniger (Hall) (glabella, free cheek, pygidium) r

In the higher transitional beds $\left\{\frac{I}{A\ 10} - \frac{I}{A\ 13}\right\}$:

Corynoides calicularis *Nicholson* c
Climacograptus strictus *Ruedemann* cc
Climacograptus spiniferus *Ruedemann* r
Climacograptus typicalis *Hall* rr (one specimen)
Diplograptus amplexicaulis *Hall* r
Lasiograptus eucharis (*Hall*) r
Mesograptus mohawkensis *Ruedemann* c
Leptobolus insignis *Hall* c
Schizambon *cf.* canadensis (*Ami*) rr
Lingula curta *Hall* c
Dalmanella rogata *Sardeson* c
Ulrichia bivertex (*Ulrich*) c
Lepidocoleus jamesi (*Hall and Whitfield*) rr

This fauna of the transitional zone is unmistakably that of the Canajoharie shale and corresponds to the lower division of the Canajoharie.

The black shale in the northern exposure, following the transitional beds has afforded to Mr. Gould:

Corynoides calicularis *Nicholson* c
Climacograptus strictus *Ruedemann* c
Mesograptus mohawkensis *Ruedemann* c
Glossograptus quadrimucronatus cornutus *Ruedemann* r
Lingula *sp.*
Schizambon canadensis (*Ami*) rr
Dalmanella rogata *Sardeson* c
Cryptolithus tesselatus *Green* cc
Calymmene senaria *Conrad*
Ceraurus *sp.*
Geisonoceras *sp.*

This upper shale mass is likewise undoubtedly of Canajoharie age and corresponds to the upper division as exposed in the Rural cemetery, Albany, N. Y.

Isolated outcrops of black calcareous shale along the east shore of Button bay, representing still higher beds of the shale formation contain:

Corynoides calicularis *Nicholson* cc
Climacograptus strictus *Ruedemann* c
Glossograptus quadrimucronatus (*Hall*)
Leptobolus insignis *Hall*
Worms (new species), like those at Rural Cemetery.

Finally, the 500 feet of black shale exposed from Arnolds bay to the Trenton limestone contains:

Mastigograptus *sp.* (fragment) rr
Corynoides calicularis *Nicholson* r
Diplograptus (Mesograptus) mohawkensis *Ruedemann* cc
Diplograptus (Amplexograptus) macer *Ruedemann* r
Diplograptus amplexicaulis *Hall* r
Diplograptus vespertinus *Ruedemann* c
Lasiograptus eucharis (*Hall*) c
Trematis terminalis *Hall* rr
Leptobolus insignis *Hall* r
Orthoceras *sp.* rr

This shale is also of Canajoharie age and appears to represent a still higher horizon than the north end of the northern shale exposures. Corynoides calicularis and Mesograptus mohawkensis are by far the most common fossils and were collected throughout the section, at over twenty stations.

Diplograptus (Amplexograptus) macer occurs in the upper beds.

It thus appears that the entire mass of black calcareous shale at Panton, representing three different horizons and altogether comprising probably as much as 1000 feet of rock, or a thickness corresponding to the maximal thickness recorded for the Vermont "Utica," belongs into the Canajoharie and not the Utica shale, and is thus of Trenton age.

On the New York side a few feet of black calcareous shale are exposed on the road from the village of Ticonderoga to Addison Junction (now railroad station Fort Ticonderoga). This shale contains:

Corynoides *sp. cf.* calicularis *Nicholson*
Climacograptus strictus *Ruedemann*
Glossograptus quadrimucronatus (*Hall*)
Lasiograptus eucharis (*Hall*)
Glossina trentonensis *Hall* c
Lingula *sp. nov. cf.* obtusa *Hall*
Ctenodonta *sp. cf.* levata (*Hall*)
Aparchites minutissimus (*Hall*) cc

This faunule indicates that also the black shale at the south end of Lake Champlain, near Ticonderoga, is referable to the Canajoharie shale.

A long exposure of black shale is found at the north end of Willsboro Point, about two-thirds down the lake, and half way between the Panton outcrops and the large outcrops of black shale on Grand Isle, Vermont. The contact or transition with the Trenton limestone was not observed. Unfortunately a strongly developed cleavage cuts this shale perpendicular to the bedding planes and this makes collecting extremely difficult. There were found, however:

Mesograptus mohawkensis *Ruedemann*
Leptobolus insignis *Hall*
Dalmanella rogata *Sardeson*
Liospira *sp.*
Triarthrus becki *Green*
Primitiella unicornis (*Ulrich*) cc
Aparchites minutissimus (*Hall*) cc

This faunule indicates the uppermost division of the Canajoharie shale and demonstrates that the latter extends northward beyond the middle of the Champlain basin.

There is but one outcrop of shale between Willsboro Point and the Canadian boundary line, that at Stony Point 1½ miles south of Rouses Point, and thus close to the international boundary. Here were found in hard, splintery, dark bluish gray calcareous shale:

Climacograptus spiniferus *Ruedemann* c
Glossograptus quadrimucronatus *Hall* c
Lasiograptus eucharis (*Hall*) r
Leptobolus insignis Hall r
Triarthrus becki *Green* cc

This faunule is characterized by the combination of Glossograptus quadrimucronatus, and Climacograptus spiniferus, with Lasiograptus eucharis and Triarthrus becki.

Climacograptus spiniferus and Triarthrus becki* point unmistakably to the eastern shale belt and a northern continuation of the Martinsburg, Snake Hill and Canajoharie shales of Pennsylvania and New York into this northern Champlain region. As to the age of the rock we infer from these two fossils that it is still older than Utica and probably homotaxial to late Trenton, a conclusion that is not contradicted by the other graptolites because they

*(Note). Triarthrus becki is a Snake hill and Canajoharie form The Utica and Frankfort form is T. eatoni Hall.

also occur in the Snake Hill and Canajoharie shales, though ranging considerably higher up.

We observed a continuation of this shale on the Vermont side of the lake at Windmill Point in the town of Alburg, where in like hard black calcareous shale the following species were obtained:

Glossograptus quadrimucronatus (*Hall*)
Lasiograptus eucharis (*Hall*)
Leptobolus insignis (*Hall*)

How far south this horizon extends in the black shale belt of Vermont we do not know, but suspect from some observations of ours that it reaches the southern extremity of Grand Isle.

One and one-half miles east of the outcrop at Windmill Point, along the lake shore at Alburg, Vermont, there were found in alternating black calcareous shale and black to dark gray impure limestone, mapped with the Utica shale by the Vermont Survey, the following forms:

Lingula (Palaeoglossa) trentonensis (*Conrad*)
Lingula *cf.* curta *Conrad* r
Dalmanella rogata *Sardeson* r
Protozyga exigua (*Hall*) r
Calymene senaria *Conrad* r
Odontopleura trentonensis (*Hall*) r
Primitiella unicornis *Ulrich* c
Primitia *sp.*
Ulrichia bivertex (*Ulrich*) r
Tetradella subquadrans radiomarginata[6] *Ruedemann* cc
Lepidocoleus *cf.* jamesi (*H. & W.*)

The most common and characteristic fossils of this faunule are Protozyga exigua, Primitiella unicornis and Tetradella subquadrans radiomarginata. These, in association with Lingula trentonensis, Odontopleura trentonensis and Ulrichia bivertex leave no doubt of the Trenton age of this dark calcare-

[6] This variety has all the characters of the Trenton species Tetradella subquadrans Ulrich, with the exception of the frill which bears distinct radiating lines, instead of being smooth, and is sharply bent up instead of being concave. Two specimens measured 2.2 mm by 1.1 mm and 2.1 mm by 1.1 mm, the variety thus having the exact dimensions of the typical form.

ous shale, which on lithologic grounds is considered as Utica shale (Perkins 1904, p. 117; 1916, p. 214).[6]

The Alburg shale contains an interesting combination of two of the characteristic ostracods of the Canajoharie shale in the Mohawk valley, namely, Primitiella unicornis and Ulrichia bivertex, with Trenton fossils not observed in the Canajoharie shale. The most common of these is Protozyga exigua, a middle Trenton species so far known only from the Watertown–Lowville region of New York. Also Lingula trentonensis is a middle Trenton species, and Odontopleura trentonensis is an element hitherto only known from the Trenton of the Bay of Quinte in Ontario. It is thus seen that the shale at Alburg forms a connecting link between the Canajoharie shale and the northern Trenton.

The shales at Cumberland Head near Plattsburg, were first noted by White (1900, p. 460) who considers them as either " very high Trenton or Utica " and cites a fauna, that is said to establish a connection between those of New York and Canada. White points out that similar rocks occur on Grand Isle, directly opposite Cumberland Head, and Cushing thinks that these are the transition beds mentioned from there by Perkins (1902, p. 114). Cushing (1905, pl. 13) has mapped these beds which he is inclined to consider as passage beds from the Trenton to the Utica as " Cumberland Head shale" and described them (ibid., p. 375) as consisting of blue-black slaty limestones and calcareous shales, with some firmer limestone bands. Ulrich, in the Revision, has correlated the Cumberland Head shale with the lower and middle Trenton, or in a general way, with the Canajoharie shale.

The writer had the pleasure of spending, in 1919, a day on Cumberland Head under the competent guidance of Prof. G. H. Hudson of Plattsburg, N. Y. It was seen that the Cumberland Head shales are lithologically very different from the Canajoharie shale of the Panton shore and the southern Champlain basin in general, for the prevailing element is slaty limestone and graptolite shale was not observed at all. The beds, as far as seen, are strangely barren in fossils. The following forms were collected:

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[6] Professor Perkins is, however, aware of the fact that not all black shale in Vermont is of Utica age, for he states (ibid, p. 208): "In Vermont, as in Canada, New York and elsewhere, there is in many of the exposures no separation between the Trenton and the Utica for while the latter is almost wholly shale and the former limestone, yet in places there is compact limestone bearing Utica fossils and shale with Trenton fossils. Moreover in some localities the Trenton passes into the Utica so far as the contained fossils indicate."

Stromatocerium *sp.*
Lasiograptus eucharis (*Hall*)
Arthrostylus *cf.* obliquus *Ulrich* (fide Ulrich)
Leptobolus insignis *Hall*
Schizocrania filosa *Hall*
Dalmanella rogata *Sardeson*
Conularia trentonensis *Hall*
Isotelus *cf.* latus *Raymond* (pygidium & pleurae)

This faunule, small as it is, suggests a lower and middle Trenton age of the beds, as before inferred by Ulrich. It is then probable that these slaty limestones are in part at least equivalent to the Canajoharie shale. They represent, however, lithologically and faunistically, a different facies, and were clearly deposited under different conditions, if not in a separate basin, and should for that reason be distinguished by a name of their own.

The " Utica " shale forms a broad belt in Vermont from the Canadian boundary line southward over the islands of the lake, especially North Hero and Grand Isle (see Perkins 1904, p. 103) and attains there a considerable thickness. This shale is described by the Vermont geologists as being remarkably barren of fossils, Triarthrus becki and "Diplograptus" being the only fossils mentioned as common in places. This combination of Triarthrus becki and Glossograptus quadrimucronatus (the "Diplograptus pristis" of the earlier authors), as well as Climacograptus typicalis which the writer has collected on Grand Isle, indicate that the Stony Point shale reaches, on the Vermont side, in pretty strong development to the middle of the Champlain basin.

There is, however, little doubt that the Canajoharie shale which reaches such great thickness along the Panton shore, only 30 miles south of South Hero, is also still represented in the lower part of the black shale mass of the island[7] and its fauna is still recognizable in the shaly limestone at Alburg, close to the Canadian boundary.

The black Ordovician, so-called " Utica " shales of the Champlain basin consist then in the south entirely of Canajoharie shale, in the north prevailingly of the Stony Point shale. In the middle they may meet; the Stony Point shale resting upon the Canajoharie shale on Grand Isle and in the Vermont portion of the northern part of the basin; while on the New York side the Canajoharie shale is replaced by the peculiar facies of the Cumberland Head shale, the latter plac-

[7] The U. S. National Museum, for instance, contains specimens (no. 15244) of Lingula (Palaeoglossa) trentonensis (Conrad) from the " Utica " of Grand Isle, Lake Champlain.

ing itself between the lower division of the true Trenton limestone and the black Stony Point shale. It seems that the zone of the Cumberland Head shales extends northward over Point de Roche and merges into the dark impure limestone of the Alburg "Utica" belt described above.

11 The Graptolite Zones of the Ordovician Shale Belt of New York

There extends a broad belt of gray and black, red and green shale and slate through eastern New York. Beginning at the Vermont state line east of Whitehall, at the head of Lake Champlain, its course runs in southwest direction to the Hudson river which it follows from Glens Falls to the neighborhood of Poughkeepsie where it crosses the river and thence proceeds, between the Shawangunk mountains and the Highlands, into New Jersey. This belt is but a segment of the long zone of the Appalachian shaly deposits extending from the south bank of the lower St Lawrence river through the province of Quebec, Vermont, New York, Pennsylvania and Maryland into and beyond Virginia.

In the latitude of Saratoga Springs and Albany another belt of gray and black shales branches off from the master belt and, running first in west and then in northwest direction, it girdles the Adirondacks on the south and west following first the Mohawk river from its mouth to its source, then passing over to the Black River valley and again following this stream to the neighborhood of its mouth near the outlet of Lake Ontario.

Originally this entire mass of shales was designated as Hudson River shale. Through the discoveries of Emmons and Ford, but principally through the work of Walcott, the lower Cambrian (Georgian or Waucobian) rocks were separated from this thick terrane. Likewise the shale belt of the Mohawk and Black River valleys was early separated into three divisions, namely, the Utica, Frankfort and Lorraine shales; for the reason that these rocks contain sufficient fossils other than graptolites for discrimination. The Hudson River terrane of the eastern shale belt, however, proved almost entirely barren of fossils other than graptolites, and as a result of this unfavorable condition it remained undivided, the whole mass being placed above the Utica and in a general way correlated with the Lorraine.

Meanwhile the graptolite zones of the Ordovician had been worked out in great detail in both Great Britain and Sweden, and Lapworth, Matthew and Gurley[8] had pointed out that several of these zones are recognizable in Lower Canada and further that their correlation indicated a pre-Utica age.

A systematic study of the graptolites of the shale belt of New York, carried on for 25 years by the writer, has brought out a series of graptolite zones, fully comparable in number and order of succession to those of northern Europe; and it is the intention of the writer to give in this place a brief synopsis of these zones; since, with the discrimination of the zones of the Utica shale just accomplished, the work seems to have been brought to a certain degree of completion, for the present at least.

Normanskill Shale

In 1901[9] the Normanskill zone and the zone of Diplograptus amplexicaulis were distinguished in the Hudson river beds, and both correlated with the lower and middle Trenton limestone and considered equivalent to the Lower Dicellograptus shale of Europe. Later investigations[10] have shown that the Normanskill shale is evidently still older than Trenton age and consists of two zones, the lower of which is characterized by Nemagraptus gracilis (*zone of Nemagraptus gracilis*) while the upper has not yet received a name, since the two zones were not yet found together in a continuous section. The latter zone, however, is recognizable in several outcrops as that at Lansingburg[11] by the prevalence of species of Diplograptus and Climacograptus, or of Axonophora in general, over the forms without axes (Axonolipa), and by the absence of Nemagraptus gracilis. It may provisionally be termed *the zone of Corynoides gracilis* because this slender type of Corynoides is very common in this horizon, and has, in its typical form, not been observed in the preceding zone.

Recent discoveries in Virginia have indicated a still greater age for the zone of Nemagraptus gracilis than was anticipated here.

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[8] For a bibliography on the graptolites, see Ruedemann, N. Y. State Mus. Memoir 7, 1904.

[9] R. Ruedemann, Hudson River Beds near Albany and their Taxonomic Equivalents. N. Y. State Mus. Bul. 42, 1901.

[10] H. P. Cushing and R. Ruedemann, Geology of Saratoga Springs and Vicinity, N. Y. State Mus. Bul. 169, 1914.

[11] See R. Ruedemann, Graptolites of New York, pt 2, N. Y. State Mus. Memoir II, p. 18. 1908.

Ulrich[12] has placed it above the typical Chazy and below the Lowville and Raymond[13] has correlated it with the Upper Chazy. The zone of Corynoides gracilis may then correspond to the Lowville and Leray periods. The later distinction of the Canajoharie and Snake Hill shales (see below, p. 122) has made it, at any rate, quite certain that all the Normanskill shale belongs below the Trenton.

Deep Kill Shale

In 1902 the writer[14] described the graptolite shales of Beekmantown age which he had discovered along Deep kill in Rensselaer county, N. Y., as the *Deep Kill shale*. These were divided into the following zones in descending order:

c Zone of Diplograptus dentatus and Cryptograptus antennarius.

b Zone of Didymograptus bifidus and Phyllograptus anna.

a Tetragraptus-zone.

In the correlation table (op. cit., p. 575) these zones were correlated with the Main Point Levis and Levis zones of Gurley and the St Anne zone of Lapworth, all in Quebec; the lower and upper Tetragraptus zones and Ellergill beds of Great Britain; and the Tetragraptus shale and the zones with Phyllograptus typus and Didymograptus bifidus, and that of Glossograptus and Didymograptus geminus in Sweden.

Schaghticoke Shale

In 1903, the presence of the zone of Dictyonema flabelliforme in the shale belt of New York was announced,[15] the beds being designated as Schaghticoke beds. The Zone of Dictyonema flabelliforme has a wide extension in northern Europe, notably Great Britain, Scandinavia and the Baltic provinces of Russia. It was there currently considered as marking the closing stage of the Cambrian, and this view was adopted by the writer. In the shale belt of New York it is the lowest graptolite horizon observable and the Schaghticoke beds rest directly upon the lower Cambrian. The occurrence, in the absence of other fossils, affords therefore no direct evidence

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[12] E. O. Ulrich, Revision of the Palaeozic Systems. Bul. Geol. Soc. of America, 22: 512. 1911.

[13] Percy E. Raymond, Expedition to the Baltic Provinces of Russia and Scandinavia, pt 1. The correlation of the Ordovician strata of the Baltic basin with those of eastern North America. Bul. Mus. Comparative Zool., Harvard College, 56: 237. 1916.

[14] R. Ruedemann, Graptolite Facies of the Beekmantown Formation in Rensselaer County, N. Y., N. Y. State Mus. Bul. 52, 1902.

[15] R. Ruedemann, Cambric Dictyonema Fauna in the Slate Belt of Eastern New York, N. Y. State Mus. Bul. 69, 1903.

of its true age, although the lithologic identity of the rocks (green and black shale with thin limestone intercalations) with that of the Deep Kill shale gives these beds the appearance of introducing a new age rather than closing an old one. Meanwhile, however, it has been recognized in Europe, especially through Moberg's work, from the accompanying biota that the Dictyonema shale introduces an extensive Ordovician transgression and therefore is properly considered as the basal horizon of that period.

Subhorizons

It was already suggested in Bulletin 69 that the Schaghticoke beds may comprise two subhorizons, for there were found, on one hand, the shale filled with Dictyonema flabelliforme on the brow of the cliff forming the south bank of the Hoosic river bed; and, on the other, the shale with Staurograptus dichotomus Emmons (=Clonograptus proximatus Matthew) in the river bed itself. The latter shale contains a few specimens of Dictyonema flabelliforme acadicum Matthew which bring the subzone under the general division of the Dictyonema flabelliforme zone. On account of the contorted condition of the rocks, which did not allow a clear decision as to which horizon was the upper one, we refrained at the time from separating the two horizons. Since, however, in Europe the corresponding horizons, namely, that of Dictyonema flabelliforme forma typica, and that of Clonograptus tenellus, are already distinguished, and further it being obvious that Staurograptus dichotomus is a closely related, vicarious form of Clonograptus tenellus, it is preferable to separate the two horizons, for there can be hardly any doubt that the Staurograptus horizon is above that of Dictyonema flabelliforme. Westergard[16] even interpolates still a third zone, that of Clonograptus tenellus and Bryograptus hunnebergensis between the zone of Dictyonema flabelliforme and that of Bryograptus kjerulfi, Clonograptus tenellus and Dictyonema norvegicum. Hahn[17] came to a similar division of the zone from his exhaustive study of the Dictyonema fauna of Navy Island at St John, N. B. He was able to distinguish a fauna of Dictyonema flabelliforme acadica and conferta, associated with Staurograptus and another, younger one, of Dictyo-

[16] A. H. Westergard, Studier őfver Dictyograptusskiffern etc., Meddelande från Lunds Geol. Fåltklubb, ser. B, no. 4, 1909.

[17] F. F. Hahn. On the Dictyonema-fauna of Navy Island, New Brunswick, Ann. N. Y. Acad. Sci., 32: 153. 1912.

nema flabelliforme ruedemanni, mixed with flabelliforme acadica, norwegica, desmograptoidea and Staurograptus.

We will thus distinguish the following zones:

b Zone of Staurograptus dichotomus.
a Zone of Dictyonema flabelliforme.

In part I of the Graptolites of New York (N. Y. State Mus. Mem. 7, 1904, p. 496), the writer has distinguished a *subhorizon of Clonograptus cf. flexilis,* a few fossils of which were found on the road from Albany to Defreestville. It was predicted there that the species of Clonograptus (flexilis, rigidus) described by Hall from Quebec would be found to represent a separate horizon between the Schaghticoke and Deep Kill horizons. Raymond[18] has since recognized this horizon as forming the base of the Point Levis series. He cites Clonograptus flexilis and C. rigidus, Tetragraptus quadribrachiatus, T. serra and T. approximatus as characteristic fossils. The next higher horizon at Point Levis is that with Phyllograptus typus, Tetragraptus quadribrachiatus and Didymograptus octobrachiatus. Also this horizon fails to be exposed in our Deep Kill section, but is probably present directly below our first horizon of the Tetragraptus bed, as indicated by the frequent occurrence there of the tetragrapti with the dominant species of Didymograptus.

Upon this follows our Tetragraptus zone of Bulletin 52. The detailed list of fossils, given in Memoir 7 (1904), page 504, however, brings out the fact that this zone is divisible into two subzones cited as bed 1 and bed 2. The first is characterized by Didymograptus nitidus and D. patulus and will be designated as the *subzone of Didymograptus nitidus and D. patulus.* The second (bed 2) is characterized by the abundance of Didymograptus extensus, Goniograptus thureaui, G. perflexilis and Tetragraptus fruticosus, T. quadribrachiatus and T. similis. We will distinguish it as *the subzone of Didymograptus extensus and Goniograptus thureaui.*

Upon this follows *the zone of Didymograptus bifidus* which is likewise divisible into two subzones, the first of which (bed 3) is characterized, besides Didymograptus bifidus, by Goniograptus geometricus, Tetragraptus

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[18] Percy E. Raymond, The Succession of Faunas at Lévis, P. Q. Amer. Jour. Sci., 38: 523. 1914.

fruticosus, Didymograptus gracilis, D. ellesae and Phyllograptus anna. We will call it *the subzone of Goniograptus geometricus and Phyllograptus anna.*

The second subzone (bed 5) is characterized by Didymograptus similis, D. caduceus, Phyllograptus typus and P. anna, besides the dominant Didymograptus bifidus. This bed shows a strange recurrence of forms, noted much earlier elsewhere, especially in Phyllograptus typus (see Point Levis section, p. 120). We will call it *the subhorizon of Didymograptus similis and Phyllograptus typus.*

Finally, *the zone of Diplograptus dentatus* also distinctly falls into two subhorizons, namely:

a That of Phyllograptus angustifolius and Retiograptus tentaculatus (bed 6)

b That of Desmograptus, (D. cancellatus, D. intricatus, D. succulentus) *and Trigonograptus ensiformis.* (bed 7)

Another common form is Climacograptus antennarius.

There occurs, however, at the Ashhill quarry at Mount Moreno near Hudson (see Memoir 7, p. 449) a horizon of the zone of Diplograptus dentatus that is distinctly older than any of the two observed at the Deep Kill. This subhorizon is characterized by the dominancy of Diplograptus dentatus and Climacograptus pungens and the frequent occurrence of Ptilograptus plumosus and Didymograptus forcipiformis, the latter a new species. It may therefore be designated *the subhorizon of Climacograptus pungens and Didymograptus forcipiformis.*

The complete list of our Deep Kill horizons is then, in ascending order:

Tetragraptus beds:

1 Zone of Clonograptus flexilis and Tetragraptus
2 Zone of Phyllograptus typus and Tetragraptus quadribrachiatus

Didymograptus beds:

3 Zone of Didymograptus
  a Subzone of D. nitidus, D. patulus
  b Subzone of D. extensus, Goniogr. thureaui
4 Zone of Didymograptus bifidus
  a Subzone of Goniogr. geometricus, Phyllogr. anna
  b Subzone of Didymogr. similis, Phyllogr. typus

5 Zone of Diplograptus dentatus
  a Subzone of Climacogr. pungens, Didymogr. forcipiformis
  b Subzone of Phyllogr. angustifolius, Retiogr. tentaculatus
  c Subzone of Desmograptus and Trigonograptus ensiformis

Canajoharie shale, Magog shale

The writer had already in 1901 (Bulletin 42) distinguished *a zone with Diplograptus amplexicaulis* in the shale belt of the Hudson River region, and since Diplograptus amplexicaulis was then considered a fossil of the middle Trenton (it is properly referred to the lower Trenton), and it was found that this zone overlies the Normanskill shale, the latter was removed from its post-Utica position into a line with the middle and lower Trenton. There were further recognized the following horizons: one with Climacograptus caudatus, Cryptograptus tricornis, Triarthrus becki. (Mechanicville, Van Schaick Island, etc.); another with Diplograptus quadrimucronatus, D. "foliaceus," D. "putillus," Corynoides "curtus," Triarthrus becki (Rural Cemetery), and still another with Diplograptus "foliaceus" and Corynoides "curtus," exposed at Waterford. These horizons were erroneously referred to the Utica and the last to the Lorraine, in adherence to the conclusions of the earlier writers (see memoir 7 correlation table, facing p. 490).

In 1908 [19] the beds from the Rural Cemetery, Van Schaick Island, as also those from Baker Falls which are characterized by Climacograptus spiniferus, were united under the zone of Diplograptus amplexicaulis and correlated with the Magog shale, exposed near the boundary of Quebec and New Hampshire, and which also contains Climacograptus caudatus and, in general, a fauna that is clearly younger than the typical Normanskill fauna and older than the Utica fauna. Climacograptus caudatus is in Europe a fossil of the zone of Dicranograptus clingani, which lies between that of Nemagraptus gracilis (our Normanskill) and that of Pleurograptus linearis (our Utica). This zone was therefore in a general way, in the before mentioned publication, placed in the middle and upper Trenton.

Field work in the lower Mohawk valley, preparatory to the mapping of the Saratoga quadrangle, led to a detailed study of this mass

[19] R. Ruedemann, Graptolites of New York, pt 2, N. Y. State Mus. Mem. 11, p. 29. 1908.

of pre-Utica shales in the upper Hudson and lower Mohawk valleys. The result of this work was published in 1912.[20]

In this paper the entire terrane of pre-Utica age, but of Utica aspect, in the lower Mohawk and upper Hudson River valley is distinguished as the *Canajoharie shale,* while the Lorraine facies, consisting of gray shale and sandstone, is termed the *Schenectady beds* and the similar beds of a more easterly situated basin or trough are called the *Snake Hill beds.* All these are of Trenton age, with the Schenectady beds possibly reaching also into Utica time.

The following graptolite horizons were distinguished in the Canajoharie shale, in descending order:

4 Zone of Climacograptus spiniferus, Diplograptus vespertinus, etc.

3 Zone of Lasiograptus eucharis, etc.

2 Zone of Glossograptus quadrimucronatus cornutus, Corynoides calicularis, etc.

1 Zone of Diplograptus amplexicaulis, Corynoides calicularis, etc.

It is, however, obvious from sections (published op. cit., p. 15 ff.) from Swartztown and Morphy creeks, that, in the shales exposed about 20 miles east of the typical Canajoharie sections, a zone precedes which is characterized by M e s o g r a p t u s m o h a w k e n s i s. This zone, while in the Morphy creek section reaching a considerable development, is in the Canajoharie section (ibid., p. 22) represented only in its last stage, on top of the basal Trenton (Glens Falls limestone). Since D i p l o g r a p t u s a m p l e x i c a u l i s does not appear until the upper part of the zone, the latter must precede the lowest zone of the Canajoharie shale, namely, that with Diplograptus amplexicaulis. We will distinguish this zone in the shales of Morphy and Swartztown creek as *zone of Mesograptus mohawkensis* and refer the zone, although but slightly represented at Canajoharie, to the Canajoharie shale.

An outcrop of shale at the Carlsbad spring near Saratoga (see Bulletin 169, p. 50) proves the presence of this zone also in the upper Hudson River valley.

The *Snake Hill beds* have furnished a rich fauna of other fossils than graptolites, but only meager graptolite faunules except in two cases. They have in common with the Canajoharie shale (see Bulletin 162, p. 64) the occurrence of D i p l o g r a p t u s a m p l e x i c a u l i s and C o r y n o i d e s c a l i c u l a r i s, but otherwise bear in both the graptolite and nongraptolite biota a

[20] R. Ruedemann, The Lower Siluric Shales of the Mohawk Valley. N. Y. State Mus. Bul. 162, 1912.

more distinctly easterly, Atlantic aspect. Here belong the shale on Van Schaick island with Cryptograptus tricornis insectiformis and the shale at Mechanicville (see Mem. 11, p. 32) with Climacograptus caudatus and Corynoides curtus comma. There is no doubt in our mind that these occurrences represent a zone that is older than any of the Canajoharie shale zones and that is equivalent or directly follows upon the shale exposed at Magog, for Climacograptus caudatus is found in Sweden only in the lowest of the three subzones of Dicranograptus clingani [21] and it is also in Great Britain [22] restricted to the zone of Dicranograptus clingani. We have further to see in Cryptograptus tricornis insectiformis, as well as in a number of the Magog species reminders of the nearness of the Normanskill fauna. This earlier zone of the Snake Hill beds may be distinguished as the *zone of Climacograptus caudatus.*

A higher horizon is exposed in black shales outcropping on both the east and west shores of Saratoga lake (see Bulletin 169, p. 97, 1914) north of Snake Hill. This shale has furnished an abundance of Dicranograptus nicholsoni, besides Diplograptus amplexicaulis, with varieties, Climacograptus spiniferus, mutations of Glossograptus quadrimucronatus, etc. This horizon of middle or late Trenton age may possibly correspond to the last one of the Canajoharie shale. The abundance of Dicranograptus nicholsoni which is a long range species is noteworthy in view of the fact that we shall meet another outburst of this European species in the middle Utica in an entirely different association of forms. We consider the combination, in a subzone, of Dicranograptus nicholsoni, Diplograptus amplexicaulis and Climacograptus spiniferus as of great interest, but of local importance only.

Utica Shale

Directly upon the Canajoharie shale in the middle Mohawk valley follows the *Utica shale.* This has been divided, in a monograph of the Cincinnatian of New York, now ready for the press[23] into three zones, namely,

[21] S. A. Tullberg; Skånes graptoliter I. Allmän öfversikt öfver de siluriska bildningarna i Skåne. Sver. Geol. Unders. Ser. C. no. 50, 1882

[22] Charles Lapworth, Gertrude L. Elles and Ethel M. R. Wood, A Monograph of British Graptolites, pt 5, Pal. Soc. 1906, p. 203.

[23] See also paper read before Pal. Soc. America, 1916. Abstract in: Geol. Soc. Amer. Bul., 28: 206.

1 Zone of Climacograptus typicalis, Glossograptus quadrimucronatus approximatus and Lasiograptus eucharis.

2 Zone of Dicranograptus nicholsoni.

3 Zone of Climacograptus pygmaeus and Glossograptus quadrimucronatus longispina.

To this is finally to be added, from the black shale of the Black River valley, the Deer River shale and Atwater Creek shale: *the zone of Climacograptus typicalis posterus and Glossograptus quadrimucronatus, forma typica.*

This zone also contains Diplograptus nexus and Climacograptus pygmaeus. It indicates a northeastern invasion.

The Lorraine beds contain graptolites but these are, for the most part, scattered and the beds not developed into graptolite shales.

Summarizing all the zones and subzones here enumerated, we get the following:

Table of Graptolite Zones of the Ordovician Shale Belt of New York

1 Schaghticoke shale
- I Zone of Dictyonema flabelliforme
- II Zone of Staurograptus dichotomus

2 Deep Kill shale
- III Zone of Clonograptus flexilis and Tetragraptus } Tetragraptus beds of Raymond
- IV Zone of Phyllograptus typus and Tetragraptus quadribrachiatus (zone inferred) } Tetragraptus beds of Raymond
- V Zone of Didymograptus
  - *a* Subzone of Didymograptus nitidus and Didymograptus patulus
  - *b* Subzone of Didymograptus extensus and Goniograptus thureaui
- VI Zone of Didymograptus bifidus
  - *a* Subzone of Goniograptus geometricus and Phyllograptus anna
  - *b* Subzone of Didymograptus similis and Phyllograptus typus
- VII Zone of Diplograptus dentatus and Phyllograptus angustifolius
  - *a* Subzone of Climacograptus pungens and Didymograptus forcipiformis
  - *b* Subzone of Phyllograptus angustifolius and Retiograptus tentaculatus
  - *c* Subzone of Desmograptus and Trigonograptus ensiformis.

3 Normanskill shale
- VIII Zone of Nemagraptus gracilis
- IX Zone of Corynoides gracilis

4 Magog shale, Van Schaick Island and Mechanicville shale
- X Zone of Cryptograptus tricornis insectiformis and Climacograptus caudatus (Probably two subzones)

5 Canajoharie shale
- XI Zone of Mesograptus mohawkensis
- XII Zone of Diplograptus amplexicaulis, Corynoides calicularis, etc.
- XIII Zone of Glossograptus quadrimucronatus cornutus
- XIV Zone of Lasiograptus eucharis
- XV Zone of Climacograptus spiniferus, Diplograptus vespertinus, etc.

6 Utica shale
- XVI Zone of Climacograptus typicalis, Glossograptus quadrimucronatus approximatus and Lasiograptus eucharis
- XVII Zone of Dicranograptus nicholsoni
- XVIII Zone of Climacograptus pygmaeus and Glossograptus quadrimucronatus longispina

7 Deer River and Atwater Creek shales
- XIX Zone of Climacograptus typicalis posterus and Glossograptus quadrimucronatus, forma typica

There are here distinguished nineteen graptolite zones. Three of these are subdivided into well-characterized subzones, so that altogether twenty-three divisions of the graptolite shales arise. Indications of still more subdivisions are not lacking.

Correlation of Zones

The temptation is great, of course, to undertake a close comparison of these zones with those established in Great Britain, mainly by Lapworth, Marr and Elles, in Scandinavia by Linnarsson, Tullberg, Törnquist and Moberg and in Australia by T. S. Hall and others. A correlation of the principal divisions or large zones has been attempted in Memoir 7 (see correlation table opposite p. 470). A more detailed correlation of the smaller divisions would require a very close comparison of the faunas of the horizons on both sides of the Atlantic which we are not prepared to institute at present, though it is obviously very desirable; for there are very apparent discrepancies in the relative succession of the biota that, in part at least, are due to different interpretation of certain species.

A case in illustration is the determination of a zone of Diplograptus putillus Hall in Scandinavia below the zone of Nemagraptus gracilis. Diplograptus putillus is here a very late Ordovician, if not a Silurian (Richmond) form; for Hall's type specimens of this minute graptolite, which is more properly referred to Climacograptus, came from the Maquoketa shale. There occurs, however, a series of similar small forms here as far down as the Normanskill shale. The writer has, in the forthcoming Monograph of the Cincinnatian of New York distinguished three species among them, as they prove to be of considerable value for the differentiation of horizons.

The general succession of the graptolite zones is strikingly alike in all parts of the world, as pointed out by the writer in the Graptolites of New York, that is, the succession is everywhere, in ascending order:

1 Beds with Dictyonema flabelliforme
2 Clonograptus and Dichograptus horizons
3 Tetragraptus horizons
4 Didymograptus horizons
5 Phyllograptus horizons
6 Nemagraptus horizon
7 Horizons with Climacograptus and Diplograptus

This succession is distinctly a phylogenetic one, as far as the series from Dictyonema through Clonograptus, Dichograptus, Tetragraptus to Didymograptus is concerned. Likewise Phyllograptus and Nemagraptus are later aberrant branches enjoying a brief period of ascendency; and the development of the Axonophora, as represented by Climacograptus and Diplograptus is an important, new departure of the graptolites in the Middle Ordovician.

The recent investigations of Raymond in Quebec (op. cit., 1914) and of McLearn[24] in New Brunswick seem to bring out the interesting fact that differences in the succession and development of the graptolite zones are already observable between New York and Quebec and New Brunswick; for the lowest Didymograptus zone does not appear to be nearly so well developed at Levis as at the Deep Kill, and most of the large specimens of the "horizontal" species of Didymograptus are, at Levis, found in the subzone of Didymograptus bifidus (Raymond, op. cit., p. 528). McLearn (op. cit., p. 55) came even to the conclusion, that "the faunas all show greater affinity with those of northwestern Europe, especially with the Lake District of England and St Davids at Caermarthenshire, Wales, than with Quebec and New York faunas." In both Canadian localities the earlier appearance of the important zone graptolite Didymograptus bifidus is especially notable. Whether this is due to a longer persistence there of the horizontal Didymograpti, or an actual earlier appearance of the guide-fossil of the zone; it indicates differences in the composition of the zones due

[24] F. H. McLearn. The Lower Ordovician (Tetragrapus zone) at St John, New Brunswick, and the new genus Protistograptus. Amer. Jour. Sci., 40: 49. 1915.

to geographic causes. Nevertheless, the general parallelism of the series of larger zones remains a fact of great importance for both stratigraphic correlation and paleogeographic investigation.

Another problem, always prominent in discussions of graptolite horizons, is that of their correlation with the normal series of littoral beds. In Scandinavia this problem is solved to a large degree by the partial interlocking of the two facies. No such help has thus far been offered the investigators in our shale belt, so far as the Lower Ordovician graptolite shales are concerned, which, besides are involved in the complex folding and faulting of the region. Nevertheless, several clues for a correlation of these shales have been obtained, which may be mentioned in this place.

One of these is the finding of a specimen of Callograptus salteri Hall in the Tribes Hill limestone by Prof. H. F. Cleland (see Ruedemann, op. cit., 1904, p. 585). The graptolite has its principal development in bed 2 of the Deep Kill shale (zone of Didymograptus extensus and Goniograptus thureaui), although it extends above and below this bed. Its prevailing occurrence in bed 2 agrees well with the correlation of the Deep Kill shale with the Beekmantown in general, and that of the Tribes Hill with the lower Beekmantown (division B) in particular.

Another clue is furnished by the finding of a characteristic graptolite of the Deep Kill fauna in the Bellefonte section of Pennsylvania.[25] This form, Airograptus (Dictyonema) furciferum, occurs in beds 2 and 3 (zone of Didymograptus nitidus and patulus) and the lower part of the zone of Didymograptus bifidus, in the Deep Kill section. It is therefore found in about the middle of the Deep Kill section.

In Bulletin 189, the species has been placed near the top of the Nittany or the base of the Axeman, while Bassler, in the Bibliographic Index, since published, refers the graptolite to the Stonehenge or the basal division of the Bellefonte Beekmantown section. Doctor Ulrich, in a letter dated April 22d, informs me that the latter is the true position of the species, and that this fact agrees with the view, at which he arrived years ago, namely, that the Schaghticoke and Deep Kill graptolite shales hold a position below the middle of the Beekmantown. This view is principally based on evidence obtained in Arkansas. " There," Doctor Ulrich writes, " the Phyllograptus occurs in the Jefferson city dolomite. Above its zone, with an unconformity intervening, comes a zone with the

[25] R. Ruedemann. Paleontologic Contributions from the New York State Museum. N. Y. State Mus. Bul. 189, p. 20, 1916.

nearest approach to the Fort Cassin fauna that I have seen outside of the Champlain valley."

The last of the Deep Kill zones that with Diplograptus dentatus has probably to be excepted from this correlation with the lower and middle Beekmantown (see below, p. 130).

The shale with *Nemagraptus gracilis* has recently been found intercalated, as Athens shale, with fossiliferous limestones in Virginia, by Prof. S. L. Powell, and Drs E. O. Ulrich and George W. Stose.[26] Raymond, after a critical survey of the evidence furnished in Virginia, considers the section as placing the Normanskill definitely as post-middle Chazy and pre-Trenton and probably upper Chazy age.

The writer[27] has in former publications correlated the last zone of the Deep Kill shale that of Diplograptus dentatus, with the Chazy limestone on the ground that it is separated from the preceding zones by a most profound faunal change, namely, that from the Axonolipa to the abruptly appearing Axonophora indicating an important break between this and the preceding zone. Similarly in Great Britain the zone of Diplograptus dentatus is placed above the Arenig and in Sweden the middle Dicellograptus shales begin with a like outburst of Axonophora, as Diplograptus, Climacograptus, Glossograptus and Cryptograptus.

This correlation of the last zone of the Deep Kill shale with the Chazy seems also to be well supported by the stratigraphic nearness of this Deep Kill zone to the Normanskill shale at several localities in our shale belt, as notably on Mount Moreno near Hudson. The descent of the Normanskill shale into line with the upper Chazy, as advocated by Ulrich and Raymond, would then close the gap between the Deep Kill and Normanskill zones.

It is expected that the true position of the Rysedorph Hill conglomerate in regard to the upper Normanskill shale zone of Corynoides calicularis and succeeding graptolite shales, once clearly recognized will furnish sufficient data establishing the age of these shales and of those intervening between the Normanskill and Canajoharie shales.

The intercalation of graptolite shale, carrying Corynoides calicularis, Diplograptus amplexicaulis and Mesograptus mohawkensis in the top of the basal Trenton

[26] See S. L. Powell. Discovery of the Normanskill Graptolite Fauna in the Athens Shale of Southwestern Virginia. Jour. Geol., 1915, v. 23. Percy E. Raymond, op. cit., 1916, p. 234ff.

[27] See R. Ruedemann, op. cit., 1902, p. 573 and op. cit., 1904, chart facing p. 490 and p. 498.

or Glens Falls limestone in the Sprakers and Canajoharie sections[28] affords evidence of a direct nature as to the Trenton age of the Canajoharie shale.

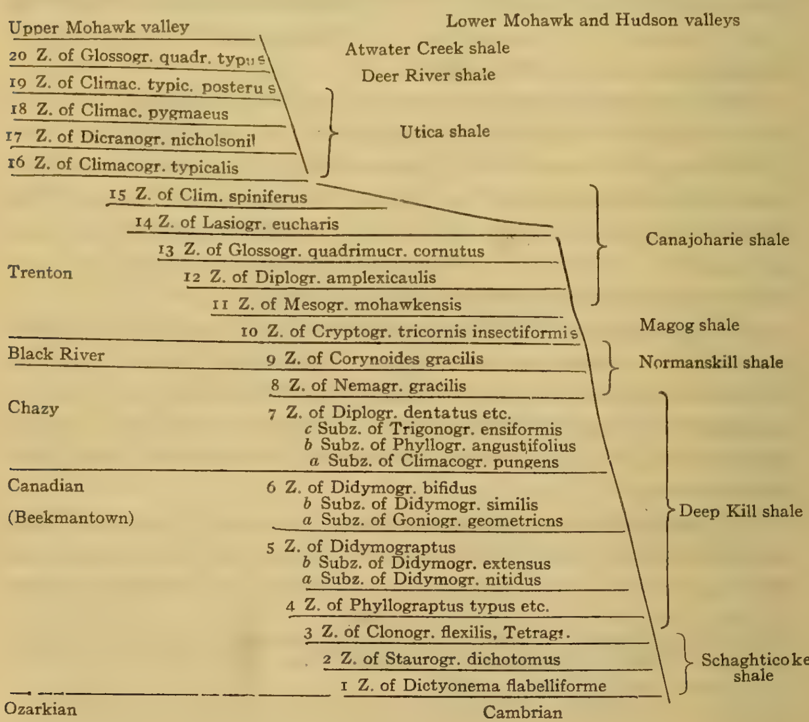
The Utica shale, like the Canajoharie and Snake Hill shales, carries mixed graptolite and nongraptolite faunas.

Summarizing these correlations of the graptolite facies with the littoral facies we get the following table of approximate correlations:

Correlation Table

Graptolite facies	*Littoral facies*
Utica shale	Utica shale
Canajoharie shale	Trenton limestone
Magog, Van Schaick Island, etc. shale	Glens Falls and Amsterdam limestone
Upper Normanskill shale	Lowville and Leray limestone
Lower Normanskill shale	Upper Chazy limestone
Upper Deep Kill (zone of Diplograptus dentatus)	Lower and middle Chazy limestone
Lower and middle Deep Kill shale	Beekmantown limestone and dolomite
Schaghticoke shale	Basal Beekmantown dolomite

DIAGRAM OF GRAPTOLITE ZONES OF ORDOVICIAN OF NEW YORK



[28] See Ruedemann, op. cit., 1912, p. 22.

New York State Museum

JOHN M. CLARKE, DIRECTOR

PUBLICATIONS

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Museum annual reports 1847–date. *All in print to* 1894, 50c *a volume,* 75c *in cloth;* 1894–*date, sold in sets only;* 75c *each for octavo volumes; price of quarto volumes on application.*

These reports are made up of the reports of the Director, Geologist, Paleontologist, Botanist and Entomologist, and museum bulletins and memoirs, issued as advance sections of the reports.

Director's annual reports 1904–date.

1904. 138p. 20c.
1905. 102p. 23pl. 30c.
1906. 186p. 41pl. 25c.
1907. (Bul. 121) 212p. 63pl. 50c.
1908. (Bul. 133) 234p. 39pl. map. 40c.
1909. (Bul. 140) 230p. 41pl. 2 maps, 4 charts. *Out of print*
1910. (Bul. 149) 280p. il. 42pl. 50c.
1911. (Bul. 158) 218p. 49pl. 50c.
1912. (Bul. 164) 214p. 50pl. 50c.
1913. (Bul. 173) 158p. il. 29pl. 40c.
1914. (Bul. 177) 174p. il. 33pl. 45c.
1915. (Bul. 187) 192p. il. 58pl. 5 maps. 50c.
1916. (Bul. 196) 308p. il. 50pl. maps. 55c.
1917. (Bul. 207, 208) 211p. il. maps. 75c.
1918. (Bul. 219, 220) 309 p. il. 43 pl. 75c.
1919. (Bul. 227, 228)p. il. maps.

These reports cover the reports of the State Geologist and of the State Paleontologist. Bound also with the museum reports of which they form a part.

Geologist's annual reports 1881–date. Rep'ts 1, 3–13, 17–date, 8vo; 2, 14–16, 4to.

In 1898 the paleontologic work of the State was made distinct from the geologic and was reported separately from 1899–1903. The two departments were reunited in 1904, and are now reported in the Director's report.

The annual reports of the original Natural History Survey, 1837–41, are out of print.

Reports 1–4, 1881–84, were published only in separate form. Of the 5th report 4 pages were reprinted in the 39th museum report, and a supplement to the 6th report was included in the 40th museum report. The 7th and subsequent reports are included in the 41st and following museum reports, except that certain lithographic plates in the 11th report (1891) and 13th (1893) are omitted from the 45th and 47th museum reports.

Separate volumes of the following only are available.

Report	*Price*	*Report*	*Price*	*Report*	*Price*
12 (1892)	$.50	17	$.75	21	$.40
14	.75	18	.75	22	.40
15, 2v	2	19	.40	23	.45
16	1	20	.50	[*See* Director's annual reports]	

Paleontologist's annual reports 1899–date.

See first note under Geologist's annual reports.

Bound also with museum reports of which they form a part. Reports for 1899 and 1900 may be had for 20c each. Those for 1901–3 were issued as bulletins. In 1904 combined with the Director's report.

Entomologist's annual reports on the injurious and other insects of the State of New York 1882–date.

Reports 3–20 bound also with museum reports 40–46, 48–58 of which they form a part. Since 1898 these reports have been issued as bulletins. Reports 3–4, 17 are out of print, other reports with prices are:

Report	*Price*	*Report*	*Price*	*Report*	*Price*
1	$1	13	*Out of print*	24 (Bul. 134)	$.35
2	.30	14 (Bul. 23)	$.20	25 (" 141)	.35
5	.25	15 (" 31)	.15	26 (" 147)	.35
6	.15	16 (" 36)	.25	27 (" 155)	.40
7	.20	18 (" 64)	.20	28 (" 165)	.40
8	.25	19 (" 76)	.15	29 (" 175)	.45
9	.25	20 (" 97)	.40	30 (" 180)	.50
10	.35	21 (" 104)	.25	31 (" 186)	.35
11	.25	22 (" 110)	.25	32 (" 198)	.40
12	.25	23 (" 124)	.75	33 (" 202)	.35

Reports 2, 8–12 may also be obtained bound in cloth at 25c each in addition to the price given above.

Botanist's annual reports 1867–date.

Bound also with museum reports 21-date of which they form a part; the first Botanist's report appeared in the 21st museum report and is numbered 21. Reports 21–24, 29, 31–41 were not published separately.

Separate reports for 1871–74, 1876, 1888–98 are out of print. Report for 1899 may be had for 20c; 1900 for 50c. Since 1901 these reports have been issued as bulletins.

Descriptions and illustrations of edible, poisonous and unwholesome fungi of New York have also been published in volumes 1 and 3 of the 48th (1894) museum report and in volume 1 of the 49th (1895), 51st (1897), 52d (1898), 54th (1900), 55th (1901), in volume 4 of the 56th (1902), in volume 2 of the 57th (1903), in volume 4 of the 58th (1904), in volume 2 of the 59th (1905), in volume 1 of the 60th (1906), in volume 2 of the 61st (1907), 62d (1908), 63d (1909), 64th (1910), 65th (1911), v. 2 of the 66th (1912) reports. The descriptions and illustrations of edible and unwholesome species contained in the 49th, 51st and 52d reports have been revised and rearranged, and, combined with others more recently prepared, constitute Museum Memoir 4.

Museum bulletins 1887–date. 8vo. (1) *geology, economic geology, paleontology, mineralogy;* (2) *general zoology, archeology, miscellaneous;* (3) *botany,* (4) *entomology.*

Bulletins are grouped in the list on the following pages according to divisions.
The divisions to which bulletins belong are as follows:

1 Zoology
2 Botany
3 Economic Geology
4 Mineralogy
5 Entomology
6 “
7 Economic Geology
8 Botany
9 Zoology
10 Economic Geology
11 “ “
12 “ “
13 Entomology
14 Geology
15 Economic Geology
16 Archeology
17 Economic Geology
18 Archeology
19 Geology
20 Entomology
21 Geology
22 Archeology
23 Entomology
24 “
25 Botany
26 Entomology
27 “
28 Botany
29 Zoology
30 Economic Geology
31 Entomology
32 Archeology
33 Zoology
34 Geology
35 Economic Geology
36 Entomology
37 “
38 Zoology
39 Paleontology
40 Zoology
41 Archeology
42 Geology
43 Zoology
44 Economic Geology
45 Geology and Paleontology
46 Entomology
47 “
48 Geology
49 Paleontology
4 Archeology
5 Zoology
52 Paleontology
53 Entomology
54 Botany
55 Archeology
56 Geology
57 Entomology
58 Mineralogy
59 Entomology
60 Zoology
61 Economic Geology
62 Miscellaneous
63 Geology
64 Entomology
65 Paleontology
66 Miscellaneous
67 Botany
68 Entomology
69 Paleontology
70 Mineralogy
71 Zoology
72 Entomology
73 Archeology
74 Entomology
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Geologic maps. Merrill, F. J. H. Economic and Geologic Map of the State of New York; issued as part of Museum Bulletin 15 and 48th Museum Report, v. 1. 59 x 67 cm. 1894. Scale 14 miles to 1 inch. 15c.
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C D Walcott

New York State Museum Bulletin

Entered as second-class matter November 27, 1915, at the Post Office at Albany, N. Y., under the act of August 24, 1912. Acceptance for mailing at special rate of postage provided for in section 1103, act of October 3, 1917, authorized July 19, 1918.

Published monthly by The University of the State of New York

Nos. 229-230 ALBANY, N. Y. JANUARY-FEBRUARY 1920

The University of the State of New York

New York State Museum

JOHN M. CLARKE, Director

GEOLOGY OF THE MOUNT MARCY QUADRANGLE, ESSEX COUNTY, NEW YORK

BY

JAMES F. KEMP

WITH A CHAPTER

ON THE PLEISTOCENE GEOLOGY BY HAROLD L. ALLING

AND A CONTRIBUTION ON THE REACTION-RIMS OF ANORTHOSITES

BY MAX ROESLER

ALBANY

THE UNIVERSITY OF THE STATE OF NEW YORK

1921

M141r-S20-1300

THE UNIVERSITY OF THE STATE OF NEW YORK

The University of the State of New York

Science Department, September 30, 1920

Dr John H. Finley

President of the University

SIR:

I beg to communicate herewith and to recommend for publication as a bulletin of the State Museum, a manuscript entitled *The Geology of the Mount Marcy Quadrangle*, which has been prepared at my request by Dr James F. Kemp.

Respectfully yours

JOHN M. CLARKE

Director

Approved for publication

John H. Finley

President of the University

Plate 1

The Ausable lakes, from Indian Face. Mount Colvin is on the left; Saw Teeth mountain on the right; and Moose mountain in the middle distance. From a photograph by George T. Ashley of Ausable Forks

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The University of the State of New York

New York State Museum

JOHN M. CLARKE, Director

GEOLOGY OF THE MOUNT MARCY QUADRANGLE, ESSEX COUNTY, NEW YORK

BY JAMES F. KEMP

I

INTRODUCTION AND PHYSIOGRAPHY

The Mount Marcy quadrangle embraces the culmination of the Adirondacks. Of all this group of mountains the two summits which rise above 5000 feet are both within its confines and of the sixteen higher than 4000 feet, it contains fourteen. Excepting the high peaks of the White mountains, where there are five which exceed Mount Marcy, and Mount Mitchell with its neighbors in North Carolina, this Adirondack dome-shaped summit stretches away toward the sky to a loftier point than do any other elevations of North America east of the Black hills of South Dakota.

Mount Marcy's true altitude was long unappreciated. Situated in the heart of the wilderness it was scarcely known until a third of the last century had passed. First the Catskills and then Whiteface were considered the highest peaks of New York. Later when the iron ores at Lake Sanford brought the settlers into the region, Mounts Marcy and MacIntyre were appreciated at their true value. Marcy, we learn, was called " Tahawus " or the " cloud-splitter " by the Indians and with all due respect to New York's great governor, one can not restrain a feeling of regret that the poetical and expressive name of the savages could not have remained attached to the peak.

The Mount Marcy quadrangle is situated between latitudes 44° and 44° 15′ and between longitudes 73° 45′ and 74° west from Greenwich. It is the third one west from Lake Champlain, as the

Elizabethtown next east of it and the Port Henry, on the lake shore, lie between. The Lake Placid sheet is north, the Santanoni west and the Schroon Lake south. The geology of the area of the Mount Marcy sheet has already been described in a preliminary way and with small scale maps, but since these little reconnaissance maps were issued, much more detailed field work has been done leading to the present report. The geology of the Elizabethtown and Port Henry quadrangles is described in detail in Bulletin 138 by the present writer and Dr R. Ruedemann; and the Paradox Lake quadrangle lying to the southeast is covered in a preliminary way by the maps and text of Bulletin 96 by Dr I. H. Ogilvie. The nearest quadrangle on the west which has been mapped is the Long Lake, whose geology is set forth by Prof. H. P. Cushing in Bulletin 115. On the south, the Schroon Lake quadrangle, has been mapped by Prof. W. J. Miller in Bulletin 213–214. To the north is the Lake Placid sheet mapped by Prof. W. J. Miller, in Bulletin 211–212.[1]

Physiography

In the broad features of its relief the quadrangle embraces a series of northeast and southwest mountainous ridges separated by rather narrow valleys. While these features appear from a study of the contour map, or better yet by observation of the country from some lofty summit, yet its most important depression, the Keene valley of the summer visitor, is almost due north and south, and the northwestern portion, containing the historic grave of John Brown, is practically a sandy and gravelly plateau on the 2000-foot contour. On the south, too, the valley of Elk lake, rather broad, open and flat, is continued almost due south down the course of "The Branch."

[1] The field work on which the present bulletin is based was begun in the summer of 1893 with Heinrich Ries as companion. Reconnaissance maps were prepared by townships on the basis of a county atlas, and were submitted with brief descriptions to Prof. James Hall, then State Geologist. In 1897 after preliminary copies of the topographic sheet were available more detailed work was done under the auspices of the United States Geological Survey, which later turned over the results to the New York survey. Upon this latter work the writer was accompanied by Charles H. Fulton. Four shorter trips have been made into the Keene valley in the intervening years to clear up obscure points. Acknowledgments are due the United States Geological Survey and Messrs Ries and Fulton. In 1914, 1915 and 1919 valuable aid was received from Harold L. Alling, at first a student at the University of Rochester and later at Columbia University but a summer resident in the Keene valley. The results of Mr Alling's studies of the Pleistocene lakes and deltas form a separate chapter toward the close of the bulletin. A second chapter on the reaction rims of garnets has been kindly contributed by Max Roesler, based on work begun under the writer's direction at Columbia University and completed at Yale University.

Notwithstanding these exceptions the large features show the great northeast structural lines, characteristic of the eastern Adirondacks and due, as one is forced to conclude, to a series of block faults, whose escarpments look away to the northwest and whose dropped sides were probably therefore in this direction. The faults have probably superimposed a later structure upon an older one, which is marked by the relatively broad and open and more mature north and south depressions.[1]

The lowest point in the quadrangle is the one where, on the 800-foot contour, the East branch of the Ausable river flows north across the boundary. All the other streams, except the little Niagara brook in the southeast corner, leave the area at altitudes above 1700 feet. The Niagara is on the 1340-foot contour, where it passes to the south.

The highest point is, as stated, the summit of Mount Marcy, 5344 feet. There is therefore an extreme vertical range of over 4500 feet. The gravelly plateau of North Elba, standing at 2000 feet and above, constitutes the most extended area of fairly flat character within the quadrangle. Nothing is known of the depth to bedrock in this portion but it may well be as much as 300 feet. The first rocky ledge revealed in the course of the West branch of the Ausable river in the Lake Placid quadrangle is over 4 miles north of the boundary of the sheet.

The mountains are in many cases of dome-shaped outline as one approaches their tops. Mount Marcy itself is a striking illustration. From a distance it resembles an umbrella without the projecting rod. Mount MacIntyre is much the same (see plate 14). The ascent of neither presents any difficulties beyond the length of the walk from the nearest shelter.

The Gothics, on the other hand, culminate in a sharp narrow ridge, and the same is true of McComb, Dix, Colvin and a few more. McComb has a little cone-shaped elevation or nipple, superimposed upon the general ridge, and is therefore easily recognized from a distance. Nippletop mountain is another of the same outline and is somewhat higher than McComb. Pitchoff mountain is a very steep and narrow ridge, between two faulted valleys, while by way of contrast Table Top mountain well justifies its name.

Escarpments. There are several precipitous escarpments within the quadrangle. The west side of Niagara mountain, in the extreme

[1] J. F. Kemp, The Physiography of the Adirondacks, Popular Science Monthly, March 1906, p. 199.

southeast corner, is well brought out by the contours. It is interesting to note the way in which the feeders of Niagara brook all come in from the western side. Escarpments hem in the lower Ausable lake on both sides. They also do the same but in less pronounced fashion for the Cascade lakes. The pass on the northwest side of Pitchoff mountain is precipitous on both sides and is impressive for this reason. All these cliffs probably are on the lines of old faults and all have doubtless been freshened up by the plucking action of the continental ice sheet.

Drainage. The mountains of the quadrangle constitute a divide between the Hudson and the Lake Champlain systems of drainage. Niagara brook and the outlet of Elk lake pass into the Schroon river and thence to the Hudson. Boreas ponds are the sources of the Boreas river which goes to the Hudson direct. Avalanche lake just east of Mount MacIntyre is one of the ultimate sources of the Hudson itself. Its outlet through Lake Colden and the Flowed Lands is the Opalescent river, which with many feeders from the Mount Marcy group of mountains passes into Lake Sanford, on whose eastern shore are the famous bodies of titaniferous magnetite.

North and southeast of Mount Dix are the sources of the Boquet river which passes through Elizabethtown and thence to Lake Champlain at Willsboro. All the other streams feed into the two branches of the Ausable river, which unite at Ausable Forks and traverse the famous chasm into Lake Champlain, south of Plattsburg.

Except those portions of the streams which practically belong to the lakes or ponds, all are swift in current, with rather steep gradients. In the small brooks are several cascades or waterfalls with a sufficient drop to afford very picturesque bits of scenery. In the larger streams but two cascades are worthy of comment. Both are on the East branch of the Ausable river; one, a mile and a half above Keene Center, and another just below the first. The river pours over rocky ledges in each instance, while elsewhere its course is usually over a bouldery bottom of drift. There is some ground for the inference that the rocky ledges mark postglacial portions of the channel, although no positive evidence in the way of borings is at hand of buried water courses running around the ledges. This subject is more fully treated toward the close of the bulletin in the chapter on the Pleistocene. The large valleys were undoubtedly existent and of approximately their present size in preglacial times, and the large features of the topography were earlier blocked out,

Plate 2

View from the summit of Mount Marcy looking due east. Taken in August 1888.

Plate 3

The gravelly plateau of North Elba, looking south to the mountains from the outskirts of Lake Placid village. The highest peak on the skyline is Mount Marcy.

The ice sheet freshened up cliffs, removed the weathered and loose mantle of débris, and filled the depressions with drift. Upon this the postglacial streams have established themselves undoubtedly following for the most part the old preglacial lines. This topic will be more fully discussed under Pleistocene geology.

In the southeastern corner of the quadrangle the brooks manifest in an appreciable degree the "trellised drainage" which is much better shown in the neighboring Elizabethtown quadrangle.

Lakes. The quadrangle is not rich in lakes as judged by the general standards of Adirondack areas. Yet several of the bodies of water present features of great scenic beauty and of much geologic interest.

The best known are the Ausable lakes, a divided pair of long, narrow character, practically forming the source of the East branch of the Ausable river. They lie in a contracted fault valley with steep rocky sides. The valley is essentially a unit, but the lakes are separated by a mile of sand and gravel, obviously the alluvial fan and delta which Shanty brook has poured into the depression so as to separate into two what was originally one. The dividing flat of gravel and sand may have some foundation of morainal materials, not now visible, but its most probable explanation is the rapid deposition of drift washed in by Shanty brook soon after the departure of the ice sheet and modified and leveled off by periods of high water in the two ponds. The flat acts as a dam for the upper lake, which stands over 30 feet higher than the lower one (see frontispiece).

The relationships are somewhat similar in the Cascade lakes, formerly called Edwards ponds and still earlier Long pond. They lie in a long, narrow, fault valley, with precipitous rocky sides. They owe their twofold character to a mass of boulders, gravel and sand and are believed to be due to an avalanche in 1830. The materials have come from the mountain on the south side and hold the western lake about 7 feet higher than its mate. The barrier of the eastern lake is a mass of boulders and sand, reinforced by vegetation, as is shown in plate 5.

Avalanche lake lies in a narrow fault valley along the eastern front of Mount MacIntyre. Its banks are so precipitous as to require a scramble for their passage. Like the other cases just cited, its waters are ponded back by a barrier of drift.

Chapel pond on the road to the southeast from Beedes (Ausable Club) is a very interesting case of a body of water confined by a long, narrow mass of drift, which now extends in a direction approximately parallel with the valley itself. The ridge is broad enough for a highway, yet on the northern side flows a small brook 30 or 40 feet below the level of Chapel pond. There may have once been a morainal mass all across the valley into which on the north side the present brook has cut, by removing the finer sand and gravel and by caving down the coarser boulders. Yet as an observer walks or drives along the highway he or she has the striking experience of viewing a pond confined by a natural dam along whose foot flows a brook entirely distinct from the outlet of the pond itself.

Elk lake, sometimes locally called Mud pond, lies in a broad, drift-filled valley and has swampy extensions. To a less degree the same is true of the Boreas ponds. Both have been enlarged by artificial dams, constructed years ago, so that with the release of the ponded waters logs could be floated down to the sawmills. The broad and open character of these two valleys, heading up as they do so quickly to divides a few miles to the north, is a peculiar feature. One would suspect the presence of the soft limestones of the Grenville series, yet in the visible ledges nothing but anorthosite has been discovered. Neither valley can well be the remnant of a large and now obliterated north and south drainage. It is by no means improbable that under the mantle of drift the old weathered limestones of the Grenville are hidden.

Glacial terraces. The mountainous sides of the Keene valley, in common with the other valleys of the region, have a pronounced series of terraces, built of deltas, deposited in successive glacial lakes. The lakes were caused by barriers, presumably of ice, to the north and standing for extended periods at definite levels. Their heights have been determined by Harold L. Alling.[1]

2

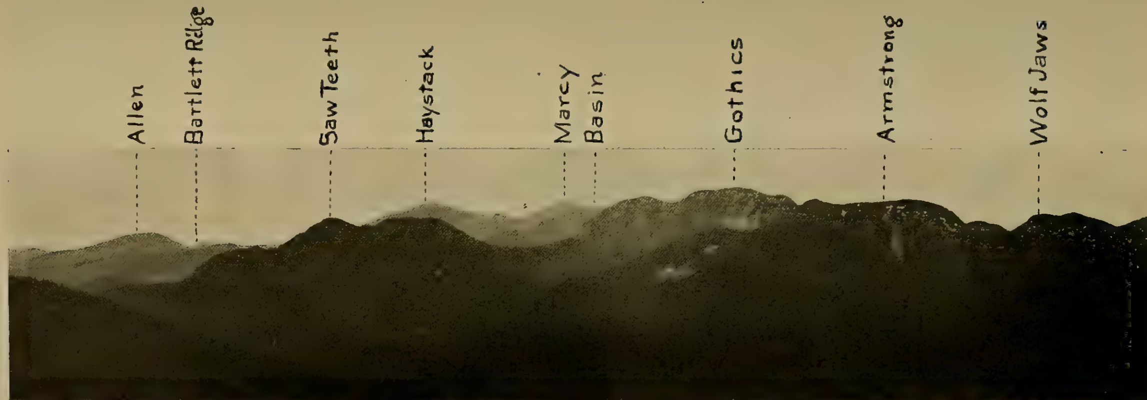
GENERAL STATEMENT OF GEOLOGICAL FORMATIONS

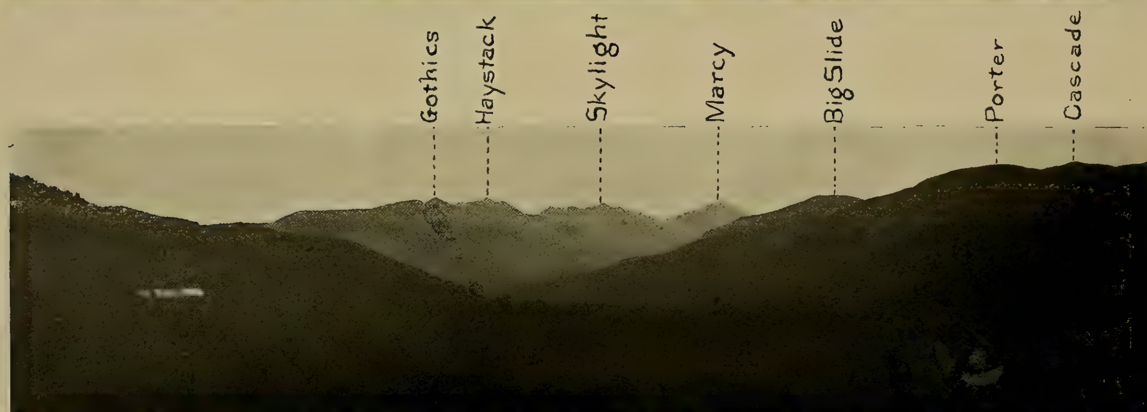
The Grenville Series and Its Contact Zones

The geological formations represented in the Mount Marcy quadrangle embrace only those of Precambrian time (with the possible exception of some basaltic dikes) and of the Glacial epoch. The geological column is as follows:

[1] See pages 70 and following.

Plate 4





Upper panorama. View toward Mount Marcy from the summit of Noonmark. Lower panorama. View toward Mount Marcy up the Johns Brook valley, from the Willey House (Hurricane Lodge), just beyond the northeast corner of the quadrangle.

Plate 5

The western (upper) Cascade lake, showing in the near foreground, the barrier between the two lakes, which is believed to be due to the landslide of 1830. At the right is the fault-escarpment of Pitchoff mountain.

Pleistocene		Deltas and modified drift	
		Moraines and eskers	
Late or Postordovician		Basaltic (Camptonite) dikes	
Precambrian		Basaltic (diabase) dikes	
	Algoman intrusives	Gabbro-syenite dikes	
		Gabbro	
		Syenite-granite series	
		Anorthosites	Whiteface type
			Marcy type
	Grenville series	Crystalline limestones	
		Quartzites	
		Paraschists	
		Paragneisses	

General summary. The glacial drift either in its original and unsorted condition or else modified by the action of water is very general in its distribution. It appears in largest amount in the valleys. There are no Paleozoic exposures, so far as is known. No positive indications of any beneath the drift have been observed but an extraordinary number of flat slabs of Potsdam is in the drift above the old Weston mine. There are a few basaltic dikes, but the number is not great. They are entirely unmetamorphosed and have clearly entered the wall rocks after the general metamorphism. Whether they are Precambrian or later in age, it is impossible to state but their petrographic characters are in some instances like those of the pre-Potsdam series described by Prof. H. P. Cushing,[1] and in others like those of the Postordovician dikes described by the writer[2] and V. F. Marsters.

The gabbro syenite dikes have been observed in only one or two places. The most interesting is on the shores of Avalanche lake where a powerful dike appears in the gulch between Avalanche mountain and Mount Colden. It cuts the anorthosite. Another has been observed in the northern entrance to Indian pass. We have no direct evidence of their ages except that they cut the anorthosites; but inasmuch as they are closely related to the basic gabbros of the Elizabethtown quadrangle on the east, and the latter are believed to be later than the syenites, these dikes are also placed later. They have strong mineralogical affinities with the syenites.

The syenites have been chiefly observed in the northern central portion of the quadrangle, where they are profoundly involved

[1] On the Existence of Precambrian and Postordovician Trap Dikes in the Adirondacks. N. Y. Acad. Sci. Trans. 1896, 15:248–52.

[2] Trap Dikes in the Lake Champlain Valley. Bulletin 107, U. S. Geol. Survey.

with the anorthosites. From relationships which have been best worked out in the Long Lake quadrangle by Professor Cushing[1] and which show the syenites to be later, the same relation is believed to hold good in the Mount Marcy. The intermingling with anorthosites is complicated as will be later set forth.

The anorthosites cover far the largest portion of the quadrangle. Practically all the southern four-fifths consist of them. They are somewhat variable in composition, the dark silicates mounting up at times beyond the characteristic percentages of the typical anorthosite. There were presumably two outbreaks; there may have been more. The anorthosites appear in large, massive exposures for the most part, but they also break through the Grenville sediments and include fragments of the latter in a very complex way. They and the syenites have brought about some remarkable contact zones with the Grenville limestones. One of these contains deposits of iron ores.

The Grenville series of sedimentary gneisses, limestones and rarer quartzites embraces the oldest rocks of all. They are limited so far as known to the northern portion of the Keene valley and the adjacent mountains. They constitute a thick series of east and west strike and steep dip. They are very ancient rocks and were metamorphosed before the intrusion of the anorthosite.

These several groups will now be described in order beginning with the oldest.

THE GRENVILLE SERIES

The oldest rocks in the Mount Marcy quadrangle are a series of sedimentary gneisses and crystalline limestones to which it is now customary to apply the name Grenville. The name is adapted from Canadian usage where it was first given by Sir William Logan to strata of the above-mentioned character in the township of Grenville, Ontario. The name has been generally adopted in the Adirondack work, where the strata are now known to outcrop in almost every quadrangle. Their most extensive development is in areas away from the central eruptive masses and the completest description thus far issued is by Prof. H. P. Cushing[2] in his description of the region of the Thousand Islands.

The Grenville series occupies a relatively small portion of the Mount Marcy quadrangle. Its best development is in the valley of the East branch of the Ausable river, for about 2 miles upstream,

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1 N. Y. State Museum Bul. 115, p. 481, 1907.
2 N. Y. State Museum Bul. 145.

Plate 6

Grenville gneiss, folded in an anticline. East branch of the Ausable river, near the northern edge of the quadrangle.

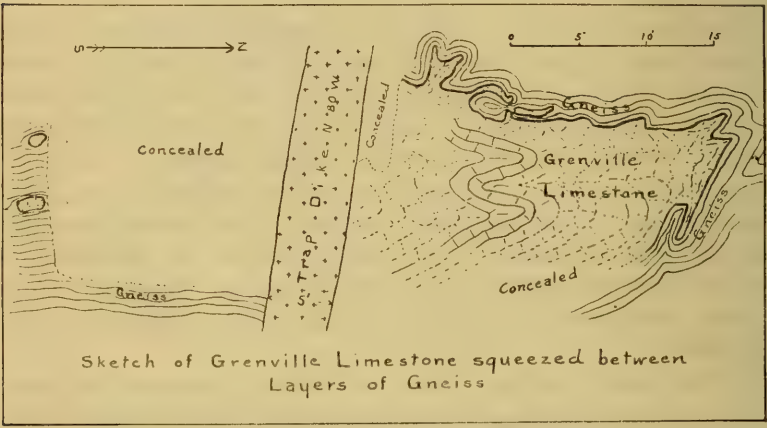
that is, south from the northern edge of the quadrangle. It extends also laterally for about 2 miles east and west but is cut by intrusive masses of anorthosite and syenite. Indeed, except for the bottom of the valley of the river the relationships with the intrusives are much confused, both here and in the neighboring parts of the Lake Placid quadrangle in the north. The river itself has washed clean a series of ledges so as to afford an extraordinarily good series of exposures (see plate 6), but as soon as one climbs the hills on either side the anorthosites and syenites seem to have penetrated the Grenville in the most intricate manner, to have produced contact zones of unusual interest and to have given rise to some bodies of magnetite in the zones, which have been the object of mining in earlier years.

The Grenville is also in evidence in a patch of limestone included in anorthosite opposite the hotel on the Cascade lakes and across the lakes from it. Apparently the Grenville limestone has been caught up in the anorthosite, and has been charged with beautiful green diopsides (coccolite) and small black garnets. Along the Cascade lakes on the northwest side, and in the pass on the northwest side of Pitchoff mountain we find again complex relations, but this time, as nearly as one can determine, the anorthosite is involved with members of the Syenite series of eruptives. These curious phenomena will be taken up under the syenites and anorthosites.

A third area is in the extreme northwestern corner of the quadrangle. A central area of limestone with wollastonite is surrounded by rusty gneisses and quartz-diopside rocks. The enormous thickness of sands, and gravels in this area prevent tracing the exposures east and south.

The most easily and certainly recognizable of the Grenville strata are the crystalline limestones which appear in beds of varying thickness. They may be but 1 or 2 feet in section, or again may reach 20 or more feet. No great section, however, is free from included masses of silicates or of fragments of the wall-rock or of intrusive tongues torn off in the great compression to which the region has been subjected. The limestones themselves are rather coarsely crystalline in texture. When recrystallized they afford very coarsely crystalline calcite, with cleavage faces over a square inch in area. The faces are then usually striated with traces of the gliding plane parallel with minus R. The limestone is also impregnated with diopside crystals of the variety coccolite. Beautiful examples may be obtained opposite the hotel on the Cascade lakes. The yellow-green of the diopside, the black of the associated garnet and the white matrix of calcite are in decided contrast. The exposure of limestone is limited and as the surrounding rocks are anorthosite, the diopsides and garnet are probably due to contact metamorphism. Colored plates 7 and 8 drawn from microscopic slides illustrate the mingling of these minerals. For these and plates 11 and 12 the writer is indebted to his friend, F. K. Morris.

The limestones show the effects of great pressure. The bent and contorted shapes of the included masses of silicates or of the tongues of basic rock apparently representing old dikes and apophyses indicate this feature in the strongest manner. Figure 1 is a sketch care-



Sketch of Grenville Limestone squeezed between Layers of Gneiss

Fig. 1 Sketch of Grenville limestone squeezed between layers of gneiss

fully made to scale of an exposure on the west bank of the Ausable river, and so near the line with the Lake Placid sheet that it is difficult to decide within which quadrange it falls. The extremely crenulated edge is sufficiently exposed to convince the observer that the limestone was molded like dough.

In the exposures at and near the pits of the iron mines formerly worked one-fourth to one-half of a mile west of the Ausable river, the limestones are associated with beds of black, granular pyroxene and with included masses of this and of magnetite in such relations as to indicate contact zones in one small case from the neighboring anorthosite; in the large instances from the syenite. They can best be described under the heading contact zones.

The thickest ledge of limestone observed in the field is found near

PLATE 7

Green diopside crystals, embedded in white calcite. Grenville limestone included in anorthosite, Cascadeville. Actual field 0.25 inch or 6 mm.

Drawn by F. K. Morris.

PLATE 8

Green diopside or perhaps hedenbergite; red garnet and white calcite, from a contact zone of Grenville limestone, west bank of Ausable river, 1½ miles south of north boundary of quadrangle. Actual field 0.25 inch or 6 mm.

Drawn by F. K. Morris.

the northwestern corner of the quadrangle on the north side of an unnamed brook. The overlying rock is not shown.

The gneisses. The limestones are associated with well-foliated gneisses, sometimes of light-colored acidic character, sometimes dark and basic. In these respects the exposures are closely similar to those in neighboring quadrangles. The chief contrasts in the large way are due to the great abundance of igneous rocks in the Mount Marcy area and to the contact effects which they have produced on the Grenville sediments. It is difficult in many cases to draw the line between regional and contact metamorphism and to be certain as to original composition and the effects of saturation and partial digestion of the sediments by the igneous masses. The gneisses are also in many cases such close parallels in mineralogy with the members of the syenite series, or else so intimately involved with the syenites that one may be sometimes in doubt as to where the metamorphosed ancient clastics end and the syenites begin.

The most acidic phase of the sediments is a rather finely granular aggregate of predominant quartz, with very subordinate plagioclase and a very little orthoclase. About one-eighth of the slide consists of irregular shreds of colorless pyroxene, presumably diopside. Plate 9 A illustrates the relations and relative amounts. The quartz, which makes up fully three-fourths of the slide, is plentifully supplied with minute needles of rutile. The specimen was found along the edge of the sheet and less than one-half of a mile northwest of Owls Head. It probably represents an old clastic sediment, associated with the limestones and originally a sandy, somewhat calcareous shale. It is similar to rocks described by Professor Cushing in Museum Bulletin 115, pages 504–8.

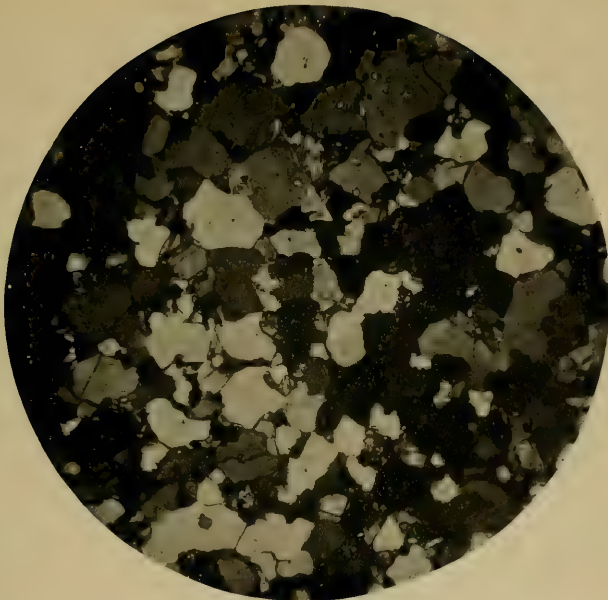
A slide of another gneiss, appearing as one of many included blocks in the anorthosite at the foot of the last steep rise of Owls Head, revealed bands of pale green, granular pyroxene, in parallel arrangement with other bands of both twinned and untwinned feldspar. The plagioclase has the extinctions of varieties somewhat more basic than the labradorite series. A few titanites and an occasional magnetic complete the mineralogy. The rock is illustrated in plate 9 B. It is reminiscent of inclusions already described from the Elizabethtown quadrangle next east (Museum Bulletin 138, pages 34–35) in which, however, quartz replaces the feldspar, here noted. These inclusions were of varying size, but in the case cited were of a foot or less in diameter. They were sharply angular and showed no corrosion or absorption. The foliation of the different inclusions ran in all directions. The phenomena are extremely significant in that they prove that the gneisses were metamorphosed before they were picked up by the anorthosite, and that this foliation, running as it does in all directions, is not the result of pressure after the blocks were caught in the intrusive. It leads one to infer the comparatively late date of the entrance of the anorthosite and the existence of a long period of time, marked by regional metamorphism before its appearance.

These inclusions are also reminiscent of observations made in the preliminary work of 1893, as set forth in the Report of the State Geologist for 1893, pages 440, 468 and 469. Along the road running northeast past Chapel pond, and amid what was believed to be at the time universal anorthosites, a small ledge was found of a dense, fine-grained rock whose composition was shown by slides to be much the same as that of the famous Saxon granulites; that is, it consisted of quartz, orthoclase and garnets. Much surprise was felt at the time that such an unexpected exposure should appear. Undoubtedly it was one of the included masses of old Grenville sediments so large as not to expose its edges in the few feet visible. The inclusion is now exposed for many feet along a fault and crushed zone, used as a borrow pit for the highway. A curious additional phenomenon which was noted for several inclusions near Owls Head, larger than those mentioned above, was shown to the writer by the late Erastus Hale of Keene Center. Mr Hale was an experienced surveyor with the dipping needle. Around the edges of the inclusions there is at times very strong attraction for the dipping needle, reaching 90°, but the amount changes within a few feet, from 90° positive to 90° negative. Apparently along the borders of the included blocks there must have been developed some small masses of strongly magnetic iron ore, even though we could not see them. At times the needle was influenced by their south polar ends, at times by their north polar.

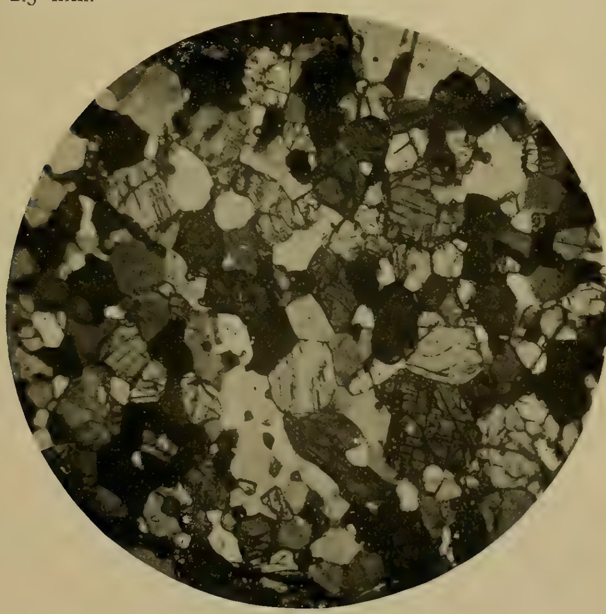
A gneiss was collected in the field on the hill just east of the East branch and one-half mile south of the northern edge of the sheet. It was encountered in ascending from the undoubted Grenville of the river bottom and was believed at the time to be a metamorphosed sediment. In thin section it revealed greatly strained microperthitic orthoclase and microcline, with irregular shreds of brown hornblende and pale green or colorless pyroxene. A little magnetite also appears. The rock is illustrated in plate 10.

The mineralogy is that of the syenites and the exposure may well represent an intrusive mass of this rock, which has penetrated the anorthosites in this area. In spite of a careful search decisive evi-

Plate 9



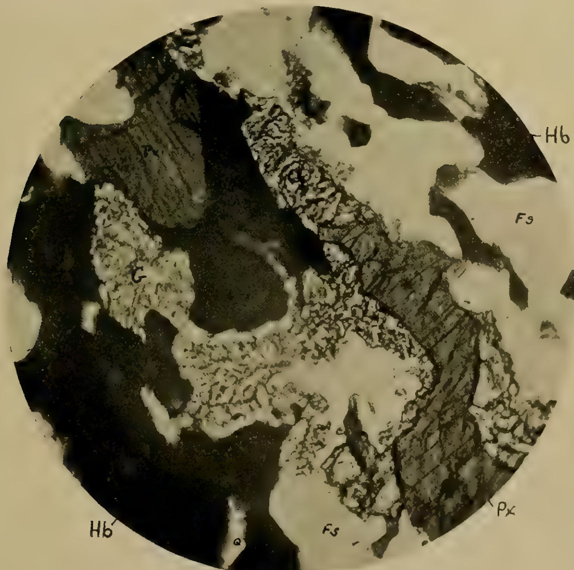
A. Grenville gneiss, northeast of Owls Head. The clear, light or gray mineral is quartz. The dark mineral is chiefly diopside. Crossed nicols, actual field 0.1 inch or 2.5 mm.



B. Inclusion of Grenville gneiss in anorthosite, just south of Owls Head. The clear or pale gray minerals are orthoclase or plagioclase. The darker well-cleaved mineral of high relief is diopside. Crossed nicols, actual field 0.1 inch or 2.5 mm.

Plate 10

A. Supposed Grenville gneiss resembling syenite. Microperthite is the pale gray mineral with numerous inclusions. The clear white or gray mineral with cleavage cracks is orthoclase. The very dark mineral is chiefly hornblende, except where the rectangular cleavage reveals pyroxene. Crossed nicols, actual field 0.1 inch or 2.5 mm.



B. Syenitic gneiss from north side of Pitchoff mountain, containing garnet (G), associated with pyroxene (Px), uralitic hornblende (Hb), feldspar (Fs), and a little quartz (Q). White light, actual field 0.08 inch or 2.0 mm.

dence, however, did not appear. One goes from one rock to the other across small valleys or gulches with fault escarpments. The same types of rock are involved in the most intimate way in the pass traversed by the old highway, northwest of Pitchoff mountain. They have been interpreted as syenites and are described as such under the syenites where the mineralogy is further discussed. A candid observer can not, however, disguise from himself the possibility that old Grenville shales may, under extreme metamorphism, assume a mineralogical composition not appreciably different from the acidic phases of the syenite series.

The basic, hornblendic phases of the Grenville are less prominent in the small areas of the Mount Marcy quadrangle than in the larger exposures of the Elizabethtown and Port Henry quadrangles already described in Museum Bulletin 138. Shaly limestones or extremely calcareous and more or less ferruginous shales could yield aggregates of hornblende, orthoclase, plagioclase, biotite and magnetite. The hornblendic rocks might also conceivably be tongues of intrusive basic syenite, crushed and sheared in the dynamic processes through which the area has passed. The peculiar green and doubtless soda-bearing pyroxene of the syenites would be a very peculiar and unusual mineral in metamorphosed sediments.

Contact zones. The best contact zones thus far discovered in the eastern Adirondacks appear in the northern edge of the quadrangle. While they vary somewhat among themselves they do present in one exposure and another very typical cases of these phenomena and some interesting variations on the general theme. They may be taken up from the simplest cases to the most complex.

Cascadeville. Many years ago early observers noted that in the talus at the foot of the mountain southeast of the barrier between the two Cascade lakes, then known as Long pond, there appeared specimens of green diopside and associated minerals in bluish calcite. The fallen blocks can be easily traced to the parent ledge higher up on the mountainside. The simplest explanation of the relations of this limestone seems to be the following: It is a mass of Grenville limestone included in the anorthosite which constitutes Cascade mountain.

The exposure of limestone at the Cascade lakes was well known to Prof. Ebenezer Emmons during his work on the second district of the State from 1835 to 1840. On pages 228, 229 of his valuable and interesting report he speaks of it as follows:

Passing now to the northwest part of the county we find several beds of primitive limestone, under nearly the same conditions as in the southern and eastern parts. Long pond is one of the most interesting; it is in the south part of Keene,[1] about 8 miles southeast of the Elba Iron Works and 4 or 5 miles from Miller's in the same town. This bed, or rather vein, was brought to light by a slide from the mountain which rises steeply from a small sheet of water known in the vicinity by the name Long pond. The vein is 20 to 40 feet wide, and occupies the highest part of the slide, being nearly half a mile from the pond. It rises out of the hypersthene rock in the form of an irregular vein or, more properly, mass. It has the usual characters, but as a whole is coarser. Some parts furnish a fine blue, calcareous spar. A fact worth mentioning is that the blue portion is confined to the surface, while the deeper situated is pale green; but on exposure to the light the latter also becomes pale blue.

This locality furnishes undoubted evidence that the limestone is an injected mass, or, in other words, a plutonic rock. The mineralogist will find in this place a rich locality of pyroxene in all its forms and varieties. In color it varies from the darkest green to nearly white. It is in fine, glossy crystals, in perfect forms, and easily obtained by blasting the limestone. Phosphate of lime in tolerable good crystals may also be obtained. Another mineral which resembles idocrase is quite common; it is in very small crystals, but it has not been particularly examined.

The limestone furnishes no tourmaline or feldspar; it is apparently more in the character of a volcanic product, furnishing particularly those minerals which are associated with lavas, as the pyroxene, amphibole, phosphate of lime, idocrase etc., while in other places the same rock shows its analogy to granite by containing tourmaline, feldspar, scapolite etc. Where the primitive limestone furnishes the latter minerals, it is in beds more widely extended, or much larger than in the former case. It is well known to mineralogists that the narrow veins of granite are more bountiful in fine minerals than the rock itself, when it occurs as one of the principal masses over a widely extended territory; in fact, under the latter form it is eminently barren, except where it is traversed by veins of the same substance of a much later period than the principal rock. In addition to the above minerals, we have found large regular crystals of scapolite, some of which now remain attached to the rocks, and are eight inches in diameter.

The mass of limestone at Long pond belongs to one of those kinds which must necessarily be quite limited in extent. It is bounded on two sides by the hypersthene rocks, and runs south in its ascent up the mountain above the slide, where it is concealed by soil, moss and the underbrush of the forest.

The above quotation is of much interest, not alone because it applies to the limestone of the Cascade lakes, but because it sets forth Professor Emmons's views on the igneous or intrusive character of the Grenville limestones. The views are not so unreasonable

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[1] The name Long pond was the original of the Cascade lakes. They are also called Edmond's pond in Watson's History of Essex County, p. 421, footnote, where it is stated that an avalanche in 1830 divided the old pond into two. Professor Emmons mistakenly uses south for north, an error that is very easy for one to make going from the southerly Hudson drainage to the northerly flowing rivers. The pond is in the northern part of Keene.

as they might at first appear. The limestones are so often molded like dough that they might easily convey to one not aware of their plasticity the impression that they were intrusive. The phenomena of contact metamorphism cover all the other features and have become much better understood since Professor Emmons wrote.

The diopside is of a beautiful yellowish green in section and somewhat darker green in the hand specimen. As is so often the case with silicates included in limestone, it is rounded as if corroded. Only rarely can the semblance of a crystal face be detected. Coccolite would be the most appropriate name for it, and by this term it has been usually described. The grains range up to one-fourth of an inch (6 mm) in diameter and exhibit the characteristic cleavage (see plate 7). They constitute about 60 per cent of the mass of some specimens of the rock. With them are associated a few scattered garnets of smaller size, black in the hand specimen, yellowish brown in thin section, and of rounded outlines. In the slide they are included in the diopside and have an isotropic core surrounded by a doubly refracting zone. The remainder of the rock is calcite.

Through the kindness of Dr G. S. Rogers, at the time instructor in mineralogy at Columbia University, an analysis of the diopside has been prepared. The crystals were separated from the calcite and were washed in dilute HCl to remove the last traces of the carbonate.

		Molec. Ratios			
SiO_2	51.84	.864			864
TiO_2	.20	2	866		
Al_2O_3	7.61	.74	84	840	
Fe_2O_3	1.75	.10			
FeO	1.02	14	760		
MnO	.12	1			
MgO	11.39	285			
CaO	25.80	460			
H_2O+	.43	24			
	100.16				

When recast we obtain

$CaOSiO_2$	53.36 per cent
$MgOSiO_2$	20.10
$FeOSiO_2$	1.98
$MgO.Al_2O_3.SiO_2$	14.95
$MgO.Fe_2O_3.SiO_2$	2.60
Quartz	6.24
SiO_2	.20
H_2O	.43
	99.86

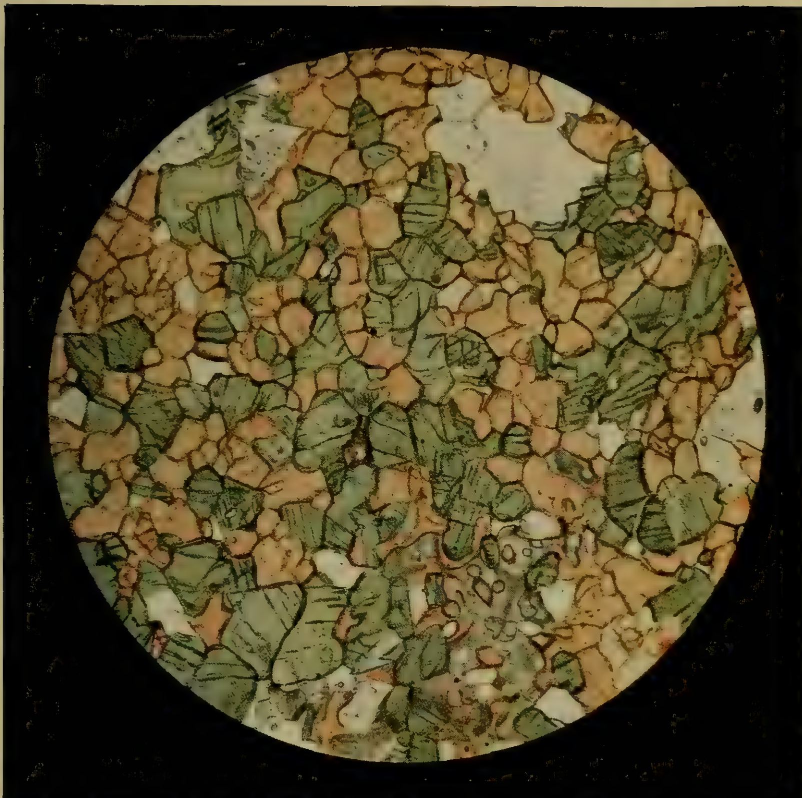
Thus about three-fourths of the mineral is the diopside molecule.

One can hardly avoid referring the development of these diopsides and garnets to the influence of the neighboring anorthosite. The mixture is indeed not unlike the original of the ophicalcites near Port Henry (see Museum Bulletin 138, page 23), where, however, the mottled rock can not necessarily be referred to contact action. At Cascadeville there is no passage to serpentine, but the diopside is beautifully bright and fresh. Garnets have not yet been noted in the ophicalcite. The geological relations are such as to suggest contact effects for these two minerals, diopside and garnet, as they are the most frequent of the lime-silicates in the undoubted zones. Below the limestone the anorthosite is cut by several basaltic dikes and contains a small exposure of magnetite.

Contacts near Owls Head. The Grenville limestones appear in a few ledges northwest from Owls Head peak just at the edge of the quadrangle. From one of these a rather fine-grained contact rock was gathered, which was almost as dense as ordinary hornfels. Under the microscope it proved to be about 70 per cent golden brown garnet, 20 per cent emerald-green pyroxene, and nearly 10 per cent quartz. The slide presents beautifully colored minerals (see plate 11). There is also another mineral, of bright aggregate polarization, which looks much like sericite as derived from orthoclase. Anorthosite ledges are frequent in the vicinity but the immediate contacts were not visible.

Contacts south of Keene Center. In the improvement of the highway along the east bank of the East branch of the Ausable river and immediately beneath the word "East" on the map, three-fourths of a mile south of its northern edge, a ledge was blasted out in the spring of 1910. The excavation brought to light a most interesting assemblage of contact minerals. The hand specimen at once revealed wollastonite and garnet, with diopside and calcite in moderately coarse aggregates. Under the microscope the same minerals appear with one or two others. Garnet in calcite is shown in plate 12. The wollastonite is broken by its cleavages into finely prismatic bundles, in the common sections, but when cut across shows the characteristic cross-sections. The garnet, while pink in the hand specimen, becomes pale yellow in the slide. It sometimes alters as shown in the accompanying sketches to some more highly refracting, almost opaque mineral in wormlike growths, which are included in the garnet itself (see plate 13 A). They resemble leucoxene more than any other mineral. The slides also contain quartz and the aggregate mineral mentioned above under the con-

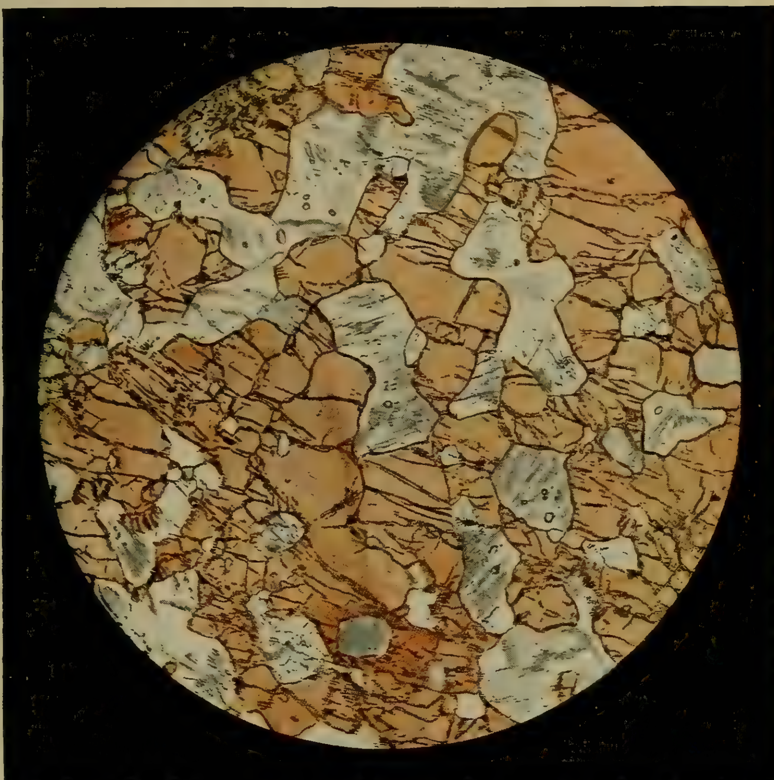
PLATE 11



Red garnet and green diopside, contact rock, northwest of Owls Head, presumably a metamorphosed limestone. The diopside is more abundant than usual. The white is quartz and the gray is probably sericite after orthoclase. White light, actual field 0.1 inch or 2.5 mm.

Drawn by F. K. Morris.

PLATE 12



Red garnet in white calcite. Contact zone south of Keene Center.
White light, actual field 0.1 inch or 2.5 mm.

Drawn by F. K. Morris.

tacts near Owls Head, which looks like sericite and is believed to be it. Less abundant than either the garnet or the wollastonite in the specimens collected in pale green diopside.

The following two analyses of the garnet-wollastonite rock were very kindly made for the writer by Dr G. S. Rogers. No. 1 is the contact rock, chiefly wollastonite and garnet, with a little calcite and diopside. A sample much richer in wollastonite is given under no. 2. No. 3, also made by Doctor Rogers, is of nearly pure garnet, from another place along the contact. The analysis yielded also MnO 0.18 not mentioned in the tabulation.

	1	2	3
SiO_2	48.17	62.56	36.29
Al_2O_3	12.69 }	2.39	10.29
Fe_2O_3	.84 }		15.05
FeO	1.41		2.92
MgO	.40	1.57	.45
CaO	34.06	28.97	32.85
Loss	1.78	3.85	1.84
Sum	99.35	99.34	99.69
Grossularite	55.91	10.38	45.45
Andradite	2.58		47.75
Wollastonite	19.64	37.66	
Quartz	12.48	34.32	
Diopside	4.75	8.44	
Calcite	4.00	8.73	
Total	99.36	99.53	

In the third analysis, the unassigned per cents are pyroxene, carbonates, water and titanic oxide. They can not be assigned without assumptions and are at best of small importance.

The analyses show that the garnet in the first two cases is chiefly the lime-alumina variety, grossularite, and as the other silicates call for no bases beyond the customary amounts in earthy limestones it is quite possible that the original sediment was an earthy limestone which had been recrystallized by the action of the igneous rock without the necessary admixture of other substances from the magma. The substances which have been driven off would be carbonic acid from combination with the lime, magnesia and ferrous iron, and water from combination with the alumina as kaolinite, and with the ferric oxide as limonite. Possibly all the silica was not originally in the form of quartz, but might have been the partially hydrated form chert. If, however, we assume that the silica was all quartz, or chalcedony, and assign the other bases to the above compounds, we can recast the analysis and obtain an original limestone of the following composition:

CaO	26.17	Calcite	46.66
MgO	.31	Magnesite	.65
FeO	1.08	Siderite	1.74
CO_2	21.49	Kaolinite	24.69
Al_2O_3	9.75	Limonite	.74
Fe_2O_3	.65	Quartz	25.52
SiO_2	37.02		
H_2O	3.53		100.00
	100.00		

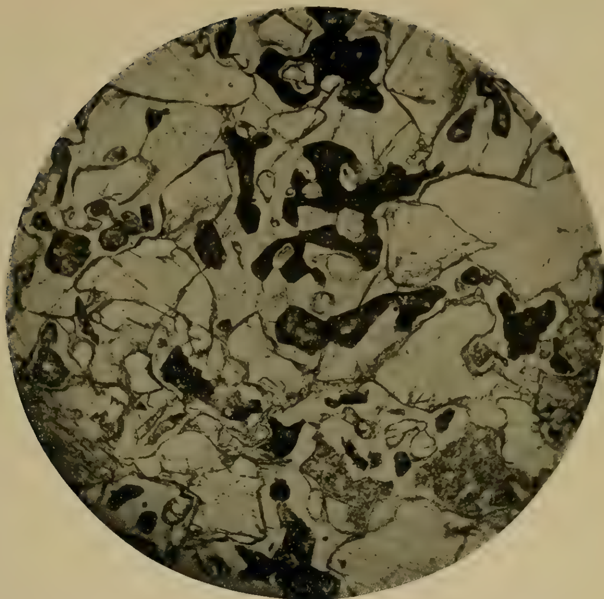
The above composition is not an impossible one for an earthy rather siliceous limestone. Such a one might have existed and have become recrystallized with no contributions of matter from the igneous rock. It is by no means certain, however, that silica was not introduced.

The third analysis with its large proportion of andradite resembles the usual run of garnets from contact zones. The composition can not well be explained without assuming the introduction of iron oxide and silica from the igneous mass.

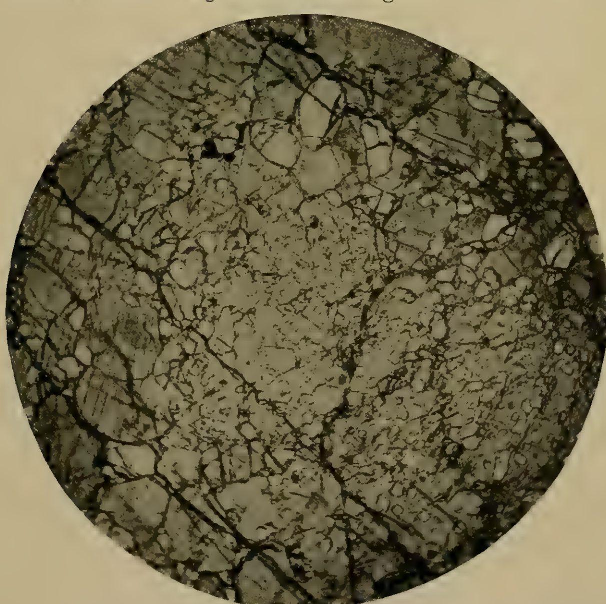
The contacts at the Weston mines. The most important of the contact effects are found to the west of the main valley of the Ausable river and reach their maximum one-half of a mile up a tributary stream which enters the Ausable from the northwest very near the edge of the sheet. The bodies of magnetite, which the contact zones contain, attracted attention as early as 1847. During the great period of activity of the bloomaries throughout the next 30 or 40 years when every water-power had its forge, its blowing engine, and trip hammer, mining operations were carried on to such a degree as to leave rather large excavations in two places, a number of exploring pits in others, and dumps which give a good idea of the geological relations. The mining ceased in 1880 and the buildings have all fallen in ruin since. The best of the early records is that left by Bayard T. Putnam in volume 15 of the Tenth Census Reports, page 118. His words may be advantageously quoted in their entirety.

The Hale mine is located at Long Pond mountain, about 1 mile southwest of the village of Keene, Keene township. It is worked by W. F. and S. H. Weston. The ore lies in white crystalline limestone. The first opening made in the vicinity is on the Wood farm, which adjoins the Hale farm on the west. The Wood mine was opened by the Westons in 1872, and was abandoned in December 1880. It produced 1120 tons of ore in the census year. The ore formed a shoot 8-16 feet wide, which dipped at a high angle to the northwest and pitched to the northeast at an average angle of

Plate 13



A. Dark wormlike alteration products from and in the garnet of the contact zone south of Keene Center. Actual field 0.1 inch or 2.5 mm. White light.



B. Many minute garnets in diopside. Contact zone south of Keene Center. Actual field 0.1 inch or 2.5 mm. White light.

45°. The pit is said to be between 250 and 300 feet deep (measured on the bottom rock of the shoot). Crystalline limestone surrounded the ore on all sides and was intimately mixed with it. From specimens seen limestone appeared to form the chief gangue.

The Hale mine was opened in the spring of 1880. A shaft was sunk 50 feet through surface material and entered what appears to be a large body of ore lying nearly horizontally in the limestone. A chamber 51 feet square has been excavated. On the east the ore pinches out; on the west it is cut by a dike, which forms the west wall of the pit; on the north there is a breast of ore 8 to 10 feet high. In places the room is 16 feet high, with ore still on the floor. Lying in the ore, are, however, layers of limestone of various thicknesses, so that this height does not represent the thickness of good ore. Not enough work has yet been done to determine definitely the shape of the ore-body; but the probabilities are that the chamber is on the top of a shoot of ore which pitches to the northward as in the Wood mine. Samples of the ore as it comes from the mine and after concentration contained:

	No. 1199	No. 1200
Metallic iron	49.37	59.92
Phosphorus	absent	0.002
Titanic acid	absent	absent
Phosphorus in 100 parts iron	0.000	0.003

Sample no. 1199 is from 50 tons "primitive ore." Sample no. 1200 is from 100 tons of "separated" ore. The chief gangue is calcite. Pyrite seems to be absent.

A brief additional note was published on the mines in 1889 by Prof. J. C. Smock, in Bulletin 7 of the State Museum, page 35, and some geological details, with a small section at the mines by the writer on the basis of observations made in 1893 (Report of the State Geologist for 1893, page 468). Not one of the observers cited was, however, impressed with the nature of the ore-bodies and their associations as contact effects. The experience of the last 10 years has been necessary to bring out these relations as they should be understood. We now realize that the ores conform to the characters lately established for many magnetite bodies and their associated lime-silicates.

The exposures extend for one-fourth of a mile or more in general direction a little east of north. They are apparently surrounded on all sides except the brook valley leading to the Ausable river, by anorthosite. In the brook valley, syenites, or at least rocks believed to be syenite appear. The anorthosite also penetrates the limestone series as the geological section later given will show. Drift is heavy and widespread, making some features a matter of inference rather than observation.

On the north the first exposures appear in an open cut, driven across the measures in a westerly direction for 40 feet. The details are shown in figure 2. About 50 feet of limestone have been caught between two masses of anorthosite. The limestone has been changed into three different varieties of rock. In one 10 or 12 feet thick, it is charged with diopside; in the next about 15 feet it has become a black, granular pyroxene which doubtless encouraged the search for ore; finally the last, about 20 feet thick, is largely changed to garnet and pyroxene, with which apatite is found under the microscope.

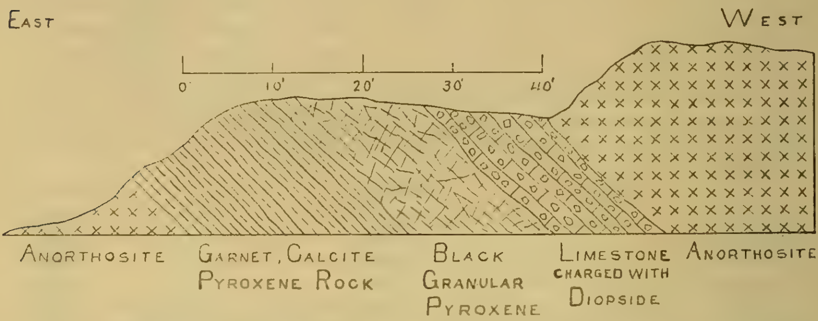


Fig. 2 Cross-section of north prospect, Weston mines, looking south. The strike is N 5 E unless compass was influenced by local attraction.

One-eighth of a mile to the south one finds another large pit now so caved as to be inaccessible. Erastus Hale of Keene Center, with whom I visited it a second time, called it the "Fifth shaft." The inaccessible rocks had an apparent dip to the west. On the dump was much limestone, charged with pyroxene, lime-silicate hornfels, consisting of green pyroxene containing multitudes of little garnets. There is also a green rock consisting of diopside about 75 per cent and calcite 25 per cent. All these rocks are undoubted contact effects, and the magnetite which was mined and of which a few stray pieces are still available, was one of the characteristic attendant features.

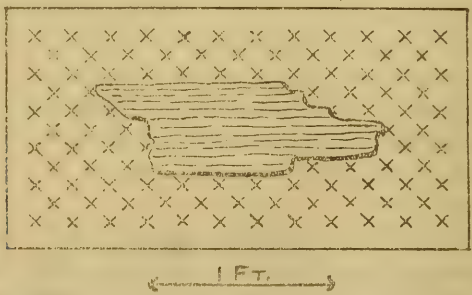


Fig. 3 Sketch of a fragment of Grenville gneiss, caught up in anorthosite. Near Fifth shaft, Weston mines.

Fifty yards above this pit and on the hillside anorthosite outcrops, in which is caught up a fragment of gneiss as shown in figure 3. It is one of many such cases in the vicinity of the Keene valley.

One-fourth of a mile or less south of Fifth shaft is a large open cut some 75 feet long and 25 feet deep now caved in with only a few old timbers sticking through the drift. It is the abandoned Hale mine. The dump, however, shows the usual limestone charged with pyroxene, and the garnet-bearing hornfels.

The largest workings of all at the old Weston or Wood mine are still farther south and in the valley of the brook which comes down from Cascade mountain. Only the old dumps and the walls of old stalls in which the ore was roasted now remain. Limestone charged with pyroxene, or with garnet, occasionally showing rude crystal outline, or with magnetite, indicate the old mineralogy. By amplifying the available material with the collections made in 1893, a very good idea of the relationships can be obtained.

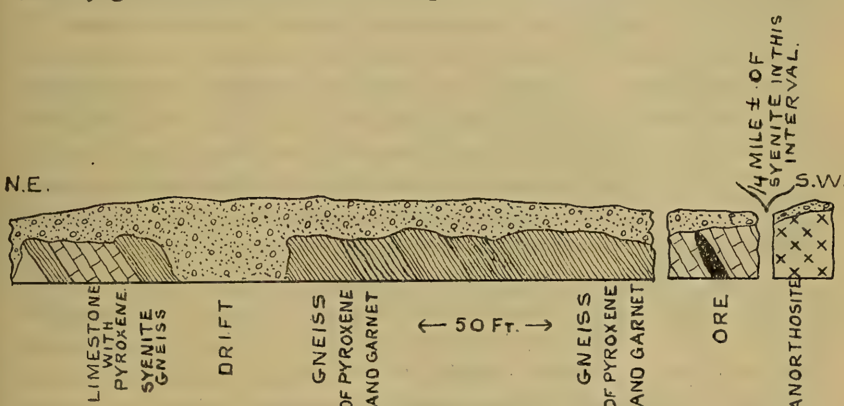


Fig. 4 Cross-section near Weston mines, looking southeast

Figure 4 is plotted from observations made in 1893, in the brook beginning with exposures to the southeast and passing upstream toward the mine. In the section the observer is looking at the south or southeast bank so that the eastern end is at the left. The gneiss first encountered varies somewhat in the slides, but the most important mineral is microperthite in irregular shreds and torn fragments showing the results of crushing and severe pressure. In the first slide it is accompanied by shreds of emerald green augite and pink garnet. A very little quartz may be present, and a very little magnetite and apatite. A tiny veinlet of quartz with a little calcite and a kaolinized selvage runs across the slide. The rock is roughly 50 per cent microperthite, and 24 per cent each garnet and augite; the others making up the remainder. It is probably a crushed member of the syenite series rather than an old Grenville gneiss. The next slide contains the same minerals with the addition of plagioclase, one crystal of the latter forming 10 per cent of the slide. The last slide shows no microperthite or augite, but is plagioclase of medium acidity and hornblende. This variation is within the limits of known changes in the syenitic rocks, and does not preclude the originals from being intrusive syenite of variable character. A short distance to the south of the mine another exposure of gneiss like the middle one described above was observed.

The gneiss is succeeded by 25 feet of ophicalcite, and this by 15 feet of gneiss, which resembles green syenite. Nearly 50 feet was then concealed, followed by a gneissoid rock, from which a specimen on microscopic examination revealed an intimate intergrowth of golden brown garnet and bright green pyroxene. It is obviously a garnet contact zone and was probably once limestone. While generally in rounded or irregular polygonal intergrowths, there are some fingerlike interpenetrations. This rock continues for 200 feet or more and was eventually succeeded by ophicalcite or pyroxenic limestone containing the ore. Of the immediate associates of the ore one could only judge from the dump. Obviously garnets, pyroxene and calcite were mixed with it. For one-fourth of a mile farther to the westward in the bed of the brook green, syenitic gneiss, richly charged with garnets can be traced in occasional ledges. The huge boulders concentrated by the brook from the very heavy moraine which fills the valley then make up the bed for one-half of a mile or more. The brook is down in a gulch in glacial drift estimated at 150 feet in vertical depth, and the boulders range up to 15 or 20 feet in diameter. They are all anorthosite. Ultimately the brook takes its rise in the anorthosite of Cascade and Porter mountains. The nature of the green syenitic gneiss is obscure. It may be intrusive syenite, but if so is extraordinarily rich in garnet, a fact which might be explained by the absorption of Grenville calcareous sediments. The gneiss may belong to the Grenville, an interpretation which would seem to be favored by the association of the limestone. The abundant garnets might then be referred to the metamorphism of calcareous, sedimentary admixtures. The former interpretation is here given preference and the exposures have been assigned as far as possible the syenitic color on the map.

In the morainal deposit in the fields above the gulch of the brook, literally scores of slabs of Potsdam sandstone can be observed. They are flat and angular, just as if transported from a ledge a short distance away. No Potsdam has ever been found in place for many miles in all directions.

The most reasonable interpretation of these observations on the ores would seem to be one involving the intrusive entrance of both the syenite and the anorthosite into the Grenville series and the production of the garnet diopside contact zones. Coincidently came the development in several places of the bodies of magnetite, which were large enough to have furnished in the old days of the local forges commercial amounts of low phosphorus, low sulphur iron ore.

Contact on the west bank of the Ausable river. One and one-half miles south of the north border of the quadrangle, and a short distance north of the bridge where the main highway from Keene valley to Elizabethtown crosses the river, is a very interesting, coarsely crystalline contact rock consisting of deep red garnets, black pyroxenes, which are a beautiful emerald green in thin sections, calcite and scapolite. The rock is illustrated in color plate 8 and in black and white plate 19A. The pyroxene is probably the variety hedenbergite, because while visibly pleochroic, green to yellowish green, it has a high extinction angle and can not be aegirite, as also remarked by Max Roesler in a contribution, later embodied in this bulletin. An extensive ledge of the garnet-pyroxene rock is exposed next the highway.

Summary of the Grenville Series

The preceding descriptions of the Grenville series will make clear that the ancient sediments are involved in a complicated way with the later intruded anorthosites and syenitic rocks. The limestones are our best preserved and recognizable originals but even they have given rise to contact zones and have been replaced with magnetite. The gneisses are chiefly microperthite-quartz rocks, with some green diopside. They are much the same as some acidic phases of the syenite series, but on the whole are believed to be old Grenville beds which may have suffered changes from the influence of the intrusives. At least three separate times the writer has returned to study the outcrops, only to find them so complicated as to prevent a more sharply defined expression than this. Much the same conditions are met in the study of similar relationships in Sweden, where the writer in 1910 in connection with the excursions of the Eleventh International Geological Congress had the opportunity to observe similar phenomena and to discuss their relationships with the Swedish geologists. Explanations involving saturation with igneous matter, digestion and assimilation alone seem to make possible a reasonable conception of their complex development. In other areas of the Adirondacks and their borders similar conclusions regarding the complexity of the relations of the Grenville with the syenite have been reached. Prof. W. J. Miller describes and maps the " Syenite-Grenville Complex " (Bulletin 126 on the Remsen Quadrangle) where the intermingling was too intimate for separation.

3

THE PRECAMBRIAN INTRUSIVES

WITH A CONTRIBUTION BY MAX ROESLER ON THE REACTIONS RIMS

The anorthosites are far the most abundant of all the rocks in the quadrangle. They are almost entirely made up of plagioclase feldspar, which itself is chiefly within the ranges of labradorite. The rocks were called " hypersthene rock " or " hypersthene " by Prof. Ebenezer Emmons,[1] who, however, recognized both the illogical practice of naming a rock after one of its subordinate minerals and also the varying mineralogy. In later years we have applied quite universally to these feldspar rocks the name anorthosite given by Dr T. Sterry Hunt in Canada in 1863. The name implies that the rocks consist essentially or predominantly of plagioclase. Hypersthene is indeed a rather frequent dark silicate in the masses of labradorite, but we also find with the microscope, hornblende and augite, and we can frequently observe with the eye alone garnet and titaniferous magnetite. The anorthosites have been quite fully described in previous bulletins [2] of the State Museum, as the detailed mapping has proceeded.

The anorthosites cover practically all but a small part of the Mount Marcy quadrangle. The area of the Grenville rocks and the Syenite series on the north alone extensively interrupt them. There are, however, in addition, some dark dikes of gabbro-syenite,

[1] Report on the Second District, p. 27–30, 1842.

[2] H. P. Cushing, Bulletin on Long Lake Quadrangle, 1907. J. F. Kemp, Bulletin 138, Elizabethtown and Port Henry Quadrangle, p. 27–37.

Plate 14

Mount MacIntyre viewed from the southeast across the Flowed Lands; a characteristic, rounded anorthosite mountain

some basaltic dikes and also some curious included masses as will be later described.

While the anorthosites are always predominantly plagioclase, they do contain varying amounts of dark silicates, which may become decidedly prominent features, especially on the borders of intrusive masses. They mark passages to the normal gabbros. In order to test the range in varieties of plagioclase by means of specific gravities, a set of eleven specimens weighing from 10 to 40 grams was selected and the specific gravities were determined in distilled water with a chemical balance amid the usual physical conditions of a laboratory. It is impossible to get representatives entirely free from inclusions or slight admixtures of heavier minerals. The specific gravities which exceed those of anorthite are due to this admixture.[1]

Newcomb	2.692	North Hudson	2.711
Essex	2.695	Schroon	2.714
Aiden Lair	2.696	Locality lost	2.717
Keene valley	2.696	Elizabethtown	2.736
Lake Placid	2.708	Locality lost	2.770
		Locality lost	2.803

It is evident that the greater number are a little below or a little above 2.700. The plagioclases range as follows:

Albite	$Ab_1\ An_0$	2.605	Labradorite	$Ab_1\ An_2$	2.710
Oligoclase	$Ab_3\ An_1$	2.649	Bytownite	$Ab_1\ An_6$	2.733
Andesine	$Ab_2\ An_1$	2.660	Anorthite	$Ab_0\ An_1$	2.765
Andesine-Labradorite transition	$Ab_1\ An_1$	2.679			

Determinations of this sort are believed to be more comprehensive than observations of extinction angles in scattered thin sections. The anorthosite may therefore be considered predominantly or essentially labradorite. The component crystals are sometimes coarsely

[1] In the valuable paper "Notes on the Lithology of the Adirondacks," 13th Annual Report, N. Y. State Museum, p. 86, 1876, the late Prof. Albert B. Leeds gives the specific gravities of forty-two specimens called norite, under which name the labradorite and other plagioclase rocks, chiefly from the Keene valley, are included. The values range from 2.67 through 3.24. An additional one of diallage at 3.386, and one of hypersthene at 3.459 are given. Since anorthite, the most basic and heaviest of the feldspars is 2.765, all values above this (no. 11 in Doctor Leeds's series) must have other heavier minerals. Analysis no. 1 of anorthosite as given two or three pages later from Doctor Leeds is no. 8 in his list, and analysis no. 2 is his no. 4. The percentages of other and heavier minerals than feldspars, as given in the results of recasting, will throw some light on the extent to which higher specific gravities call for pyroxenes, garnet, ilmenite and other heavier minerals. Evidently basic gabbros or basic syenites as we now know the rocks, must be included in Doctor Leeds's list. Unfortunately he gives the localities of only the two or three analyzed, so that we can not trace the others.

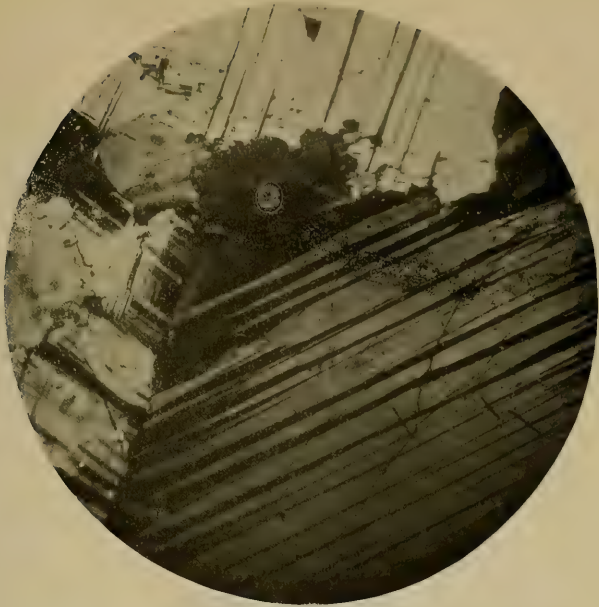
tabular and are arranged with their flat sides parallel in a rude flowing arrangement. Under the microscope the labradorite presents broad crystals consisting of multiple twins. As is so often the case with rocks of the gabbro family, the labradorite is often charged with minute inclusions, such as small brown rods, blebs and unidentifiable dust. There seems no reason to doubt that as elsewhere these minute particles are fragments of pyroxene, spinels and ilmenite. The greatest difficulty in the accurate study of the anorthosite lies in the widespread granulation to which it has been subjected. Exposures of perfectly crystallized rock are less frequently seen. They are best developed in the southwestern and southern portions of the quadrangle. Generally, however, the labradorite is crushed and granulated around a central nucleus which may survive. Stages can be traced from uncrushed originals, at times of very coarse texture, with components comparable to rather coarse pegmatites; through those whose feldspars have granulated edges; through others in whose granulated mass only remnants of the original labradorite survive; to a final stage of complete granulation which has left a pulp of small fragments of labradorite.

Coincident with the crushing the circulation of groundwaters seems to have taken place. In some specimens serious changes to scapolite and calcite have developed, producing the old-time aggregate called saussurite. The severe scraping, however, which the region has suffered from the continental ice sheet has tended to clean away the softer varieties, and leave only bright, fresh rock.

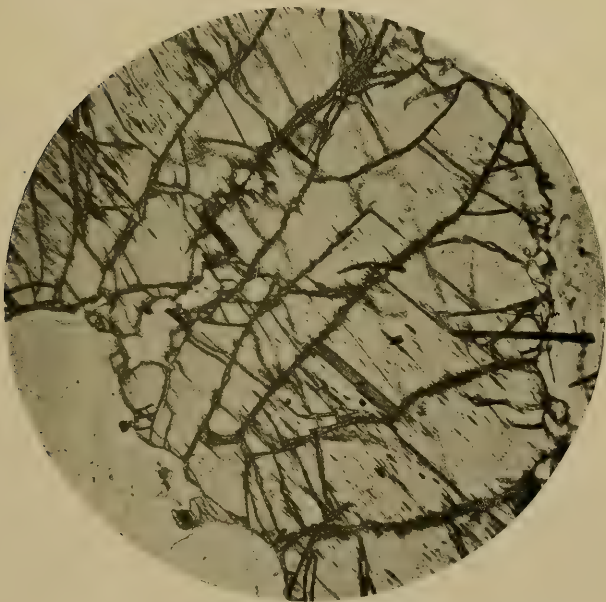
The coarser varieties of the less granulated or ungranulated anorthosites sometimes display the irridescent play of colors characteristic of labradorite, a feature that may be observed in the smooth bottoms of cascading brooks. Doubtless the name Opalescent river for the stream on the west slope of Mount Marcy was suggested by this feature.

The anorthosite displays at times appreciable amounts of the bronze-colored, faintly irridescent hypersthene, which attracted the special attention of early observers. The hypersthene has irregular outlines and under the microscope reveals the usual features of the mineral. The chemical composition of a specimen from the summit of Mount Marcy was determined in 1875 or 1876 by the late Prof. Albert B. Leeds of Stevens Institute and is given in the valuable paper entitled "Notes upon the Lithology of the Adirondacks,"[1] to which reference has already been made on an earlier page.

[1] Thirtieth Annual Report of the New York State Museum, 1876, p. 79. The analysis of hypersthene is on page 25 of the repaged reprint.



A. Uncrushed anorthosite showing the twinning of the labradorite. The original rock was almost black in color and was obtained at the southwest border of the quadrangle, west of the Boreas ponds. Crossed nicols, actual field 0.1 inch or 2.5 mm.



B. Part of a large augite crystal in the anorthosite, figure in A, above. White light, actual field 0.1 inch or 2.5 mm.

		Mol. ratio	
SiO_2	50.33	.838	.8388
TiO_2	.07	.0008	
Al_2O_3	3.36	.033	.039
Fe_2O_3	1.03	.006	
FeO	19.40	.272	.817
MnO	.71	.010	
MgO	21.40	.535	
CaO	2.77	.049	
H_2O	1.14	.063	
	100.21		

Obviously the mineral contained chiefly MgO,SiO_2, FeO,SiO_2, with a little MnO,SiO_2. Presumably the CaO was present in some monoclinic pyroxene or in some admixed labradorite, combined with the alumina and silica.

The next dark silicate in relative importance, if indeed it does not exceed the hypersthene in actual frequency, is augite, which is emerald green in thin section. It is illustrated in plate 15B. Presumably the same mineral is described by Professor Leeds under the name diallage, a name now much less used than formerly. His analysis follows.

		Mol. ratio		
SiO_2	46.28	.771	778	
TiO_2	.59	.007		
Al_2O_3	7.38	.072	86	682
Fe_2O_3	2.21	.014		
FeO	14.80	.206	596	
MgO	8.91	.222		
CaO	18.78	.168		
H_2O	1.115			
	100.065			

It is evident from the molecular ratios that we have an excess of silica no matter what well-known pyroxenic molecules we assume. If we recast by assigning all the alumina to the anorthite molecule so as to use twice as many silicas, we are still confronted with an excess. There must have been some free silica in the sample in order to conform with the percentages, or else some included feldspar with the albite molecule, whose soda was not determined.

Hornblende has been occasionally noted in the anorthosites and biotite also. Biotite is not often seen in the Mount Marcy quadrangle. It is far more abundant in the anorthosites of the southeastern portion of the Ausable quadrangle. Titaniferous magnetite, the mechanical intergrowth of magnetite and ilmenite, is scattered at times through the anorthosites in association with the bunches of dark silicates. No great masses of it have been discovered in the

Mount Marcy quadrangle comparable with those on Lake Sanford to the west, where it forms important bodies of ore.

Three analyses are available of the anorthosite from localities within the Mount Marcy quadrangle. Two were made by Prof. Albert B. Leeds (1 and 2 below). The sample for 1 was the coarsely crystalline variety of uncrushed feldspar from the summit of Mount Marcy. No. 2 is the granulated variety and was regarded by Doctor Leeds as the ground mass of a porphyritic rock. The locality is not stated in his paper. No. 3 has been specially made for this bulletin by Dr C. A. Joüet, at the time of the department of chemistry at Columbia University. The analysis was based on a large sample from the High Fall, Giant Trail. The rock was a more pyroxenic variety than the other two.

	1	2		3
SiO_2	54.47	54.62		52.37
Al_2O_3	26.45	26.50		24.68
Fe_2O_3	1.297	0.757		1.24
FeO	0.665	0.565		3.49
MgO	0.69	0.74		2.00
CaO	10.80	9.88		10.57
Na_2O	4.37	4.50		4.02
K_2O	0.92	1.23		0.86
H_2O+	0.53	0.91		0.90
Total	100.192	99.702		100.13
Sp. grav.	2.72	2.70		not det.
Quartz	1.62	1.56	Deficit	.90
Orthoclase	5.004	7.23		5.00
Plagioclase	84.186	82.20		80.52
Magnetite	1.856	.93		1.62
Kaolinite	2.58	3.87		
Water	.15	.11		.90
Diopside and hypersthene	4.616	4.30		12.86
Light-colored minerals	6.472	93.97		85.52
Dark-colored minerals	93.39	5.23		14.48
Plagioclase	$Ab_1\ An_3$	$Ab_1\ An_{2.4}$		$Ab_1\ An_{2.64}$

1 Anorthosite, summit of Mount Marcy, A. B. Leeds, N. Y. State Mus. 30th Ann. Rep't, 1878, p. 92.

2 Anorthosite, granulated variety. Probably Keene valley. A. B. Leeds, as under 1.

3 Pyroxenic anorthosite, High Fall, Giant Trail, C. A. Joüet, for this bulletin. Previously published in N. Y. State Mus. Bul. 138, p. 36, 1910.

All these analyses show that the rock is nearly all labradorite, but that minor though variable amounts of the bisilicates and magnetite are associated. Doctor Leeds in discussing his two analyses develops the elaborate calculations which were practised by the mineralogists and petrographers of forty years ago, and which have become so much simplified in the years since then.

The anorthosites as just passed in review come under the variety characterized by blue to very dark, almost black plagioclase, which in the greater number of exposures is to a greater or less degree granulated around the margins of the crystals. They belong to the Marcy type as named by W. J. Miller. We have some evidence that in the Mount Marcy quadrangle, as in the Elizabethtown, inclusions of an older consolidated variety have been caught up in a later irruption. On the northern slopes of Baxter mountain such inclusions have been detected by H. L. Alling and furnish some parallels with the observations recorded in Bulletin 138, pages 37–39. On Baxter mountain, however, gneissoid anorthosite is included in one of more massive texture. Apparently an older and probably viscous, cooling mass was given a gneissoid character by frictional drag near the edge. After it had chilled a renewed outbreak of still molten matter from the depths, penetrated and included fragments of the older chill.

The Whiteface type. On the extreme northeast corner of the quadrangle, where the anorthosites of the usual variety are in association with the Grenville strata, the plagioclase takes on the white color characteristic of the Whiteface type. The exposures are of such limited extent as compared with the great area of the Marcy type, and the type has been so well recognized as a border phase by the writer[1] and by H. P. Cushing[2] that no further discussion is called for at this point.

From the anorthosites to the syenites there are some passage forms. We note at times in the anorthosite microperthitic developments which are much more characteristic of the syenites. In the syenite rocks in the mountains north of the Cascade lakes we may sometimes see large blue, rectangular labradorites in ledges apparently of green syenites. An intermingling of the two rocks is a feature of Pitchoff mountain. The observer is almost at a loss to decide where one ends and the other begins. Beneath the iron bridge which crosses the East branch exactly a mile south of the northern edge of the quadrangle, ledges of syenite are again extensively exposed and contain blue labradorite crystals. Either an intermediate magma has led to their development, or else the later syenite has absorbed older anorthosite almost but not quite to extinction.

Inclusions in the anorthosites. On an earlier page in speaking of the Grenville gneiss, several inclusions in anorthosite were

[1] Kemp, J. F., N. Y. State Mus. Bul. 138, p. 35–37.
[2] Cushing, H. P., N. Y. State Mus. Bul. 95, p. 310–12.

described, which cast some light on the nature of the Grenville rocks. Others have, however, been noted which are anomalous. On the trail to the summit of the Gothics, inclusions were found by the writer as early as 1898 both at the summit and about 200 yards below it. In 1915 they were discovered still more abundantly by H. L. Alling. The one on the summit was about a foot in diameter and appeared to be a mass of gray gneiss, roughly rhomboidal in shape. Under the microscope about three-fifths of the slide is plagioclase, with the extinctions of labradorite and often micro-

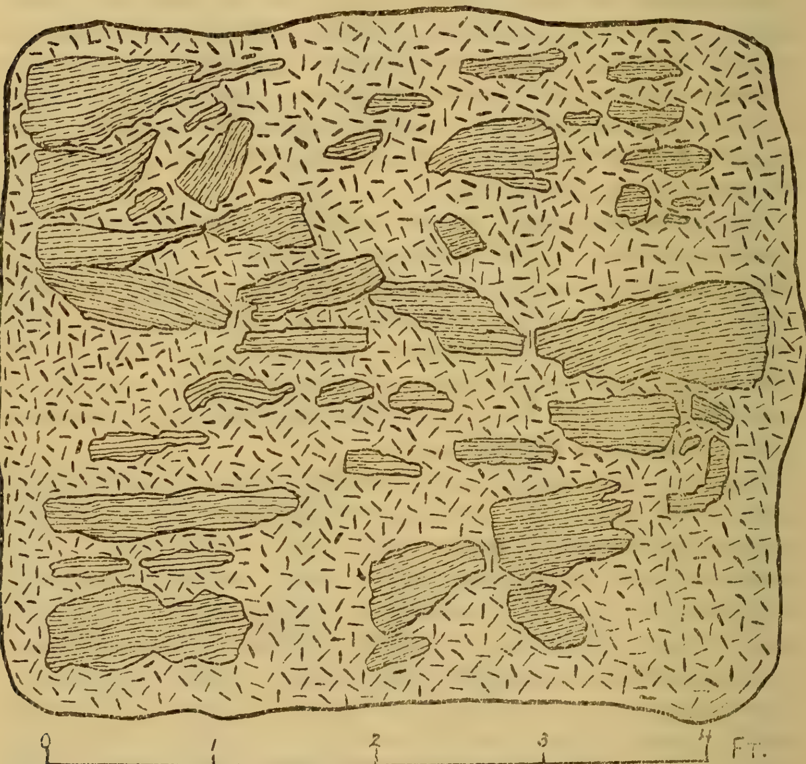


Fig. 5 Detail of dark, gneissic inclusions in anorthosite, Roaring brook, Giant trail

perthitic. The two-fifths of dark silicates are chiefly hypersthene. Brown hornblende is subordinate and red garnet occasional. Magnetite is common. The grain is fine, ranging from 0.1–0.2 mm in diameter. The mineralogy reminds one of the dark rock which appears in the Avalanche lake dike and in at least one other exposure, but the feldspar is more abundant and the explanation of small angular fragments in a great anorthosite mass is difficult. The inclusion and others in the vicinity are undoubtedly fragments of Grenville sediments which have been saturated with anorthosite magma.

A very peculiar exposure appears on Roaring brook, along the trail up Giant from the Keene valley. The area is very near the border of the Elizabethtown quadrangle and may be in the latter. It has been mapped on the Elizabethtown sheet as a small syenite area in the anorthosite. Anorthosite is the most extensively exposed country rock. In the valley of the brook it shows extraordinary brecciated contacts with the darker rock, which was earlier interpreted as a basic syenite but which, despite mineralogical parallels with the syenites, is now believed to be Grenville. The accompanying figure (figure 5), is a sketch to scale of the dark inclusions, and the succeeding figure (figure 6), is of a fragment of gneissoid rock, whose minutest crenulations were parallel with the contact.

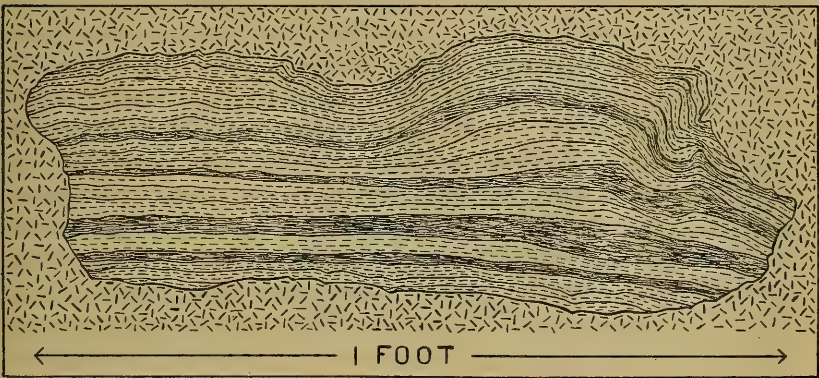


Fig. 6 Detail of an inclusion of Grenville gneiss in anorthosite, Roaring brook, Giant trail

In Bulletin 138 (page 39) mention is made of a peculiar dark rock which appears near the woolen mill, about a mile west of the large hotels of Elizabethtown on the main road to the Keene valley. In the bed of the brook which furnished the mill with power were formerly exhibited excellent contacts against the anorthosite. The relations are illustrated in detail in figure 7 of Bulletin 138. A recent freshet has now buried them in sand. The rock was a dark, gneissoid variety of moderate coarseness of grain. While showing some blue labradorite phenocrysts, it chiefly consisted of deep green pyroxene, plagioclase, orthoclase, quartz, garnet, magnetite, apatite and pyrrhotite. Two analyses were given showing marked contrasts of composition.

An exposure of what appears to be the same peculiar rock is to be seen in the Mount Marcy quadrangle in the bed of Johns brook just below its junction with Ore Bed brook and Slide Mountain brook. A second series of exposures appears in the cascading portion of another brook which comes down to Johns brook from the northwest side of Wolf Jaws mountain. The writer's early observations have again in this instance been corroborated and amplified by H. L. Alling.

In the field one would be inclined to regard the rock as a member of the basic gabbro series, but upon examination with the microscope it is found to be very different both in mineralogy and texture. The rock consists of irregularly shaped crystals of variable sizes and in places apparently granulated from crushing. The chief feldspar is orthoclase, at times microperthitic. Carlsbad twins may be detected. The microperthite is very fine, much more so than in the general run of Adirondack rocks. There is some plagioclase, but the extinction angles generally seem too small for labradorite, and indicate a more acidic variety. In at least one slide quartz is in notable amount. The dark silicate is emerald green augite, sometimes in relatively small anhedra, that is, 0.1–0.2 mm, sometimes in large ones, 0.5–3.0 mm. Strong pleochroism, green to pale yellow, may be obtained in favorable sections. The augite is in broken fragments of most irregular outline. There are a very few shreds of hornblende and biotite. The rock is richly provided with pink garnets, which in small and large anhedra are disseminated through and among the other minerals. They are at times in elongated shapes in plagioclase apparently developed from certain favorable lamellae. In amount the garnets rank well up with the feldspar and augite. In one slide titanite in unusually large irregular masses, 1.0–2.0 mm, is very prominent. Ilmenite altering to leucoxene, together with apatite, and rarely pyrrhotite concludes the list of components.

Apparently this rock can be satisfactorily explained only as an old, surviving mass of Grenville gneiss, which became involved in the intrusive anorthosites and affected with more or less of the anorthosite substance. It shows the characters of both rocks. The result has been a dark rock, resembling to the eye the basic gabbros, containing at times large blue labradorite crystals, yet not agreeing with the basic gabbros when studied with the microscope. This explanation would remove also certain difficulties met in other exposures, which have been referred not unnaturally from the variable mineralogy sometimes to the syenites, and sometimes to the gabbros. In the exposures at the woolen mill locality in Elizabethtown there was some evidence of anorthosite tonguing into the dark, supposed gabbro. This was a relation attributed to pressure effects, when the dark rock was classed with the basic gabbros which are later in age than the anorthosites. If, however, the dark rocks are surviving inclusions of Grenville sedimentary gneisses impregnated with matter from the anorthosites, the resemblance now to gabbros and now to syenites might be reasonably explained, as would also the apparent older age of the dark rocks. Exposures are as a rule limited. They run a short distance along a brook bottom, and then disappear beneath the drift or forest growth.

Besides the inclusions already mentioned there are often seen on the mountains adjacent to the Keene valley and in the northern half of the quadrangle, large masses of brown, rusty gneiss caught up in the anorthosite. They vary from a foot or less across and 5 to 10 feet long, to other hundreds of feet in each diameter. Sometimes rather pure quartz-orthoclase rock, they at other times (and especially the small ones) are rich in garnet and dark silicates. Much uncertainty has been felt in their study as to whether they were intrusive masses of syenites, as suggested by their weathering a rusty brown; or whether as is demonstrated by the small, angular individuals, they are inclusions of some older rock in the anorthosite. Difference of opinion might well arise in regard to the large masses, whose peripheral relations are obscure. But even in the case of some of these, the anorthosite appeared to cut in under them and to support the view that they are old inclusions of Grenville gneiss. They appear on Baxter, Hopkins, Big Slide, Porter, Roosters Comb, Gothics, and doubtless other peaks. An instance at the summit of Giant mountain in the Elizabethtown sheet was interpreted in Bulletin 138 as a syenite dike. Additional experience has led, however, to the interpretation here favored.

In Bulletin 170, on the North Creek quadrangle, Prof. W. J. Miller has mapped an unusual number of large and small intrusive masses of basic gabbro and has applied to them very careful microscopic and statistical mineralogical study, whose tabulation is given on page 29. Expressed in percentages by volumes the values for orthoclase are to those for oligoclase-labradorite as 32:10, 32:20, 50:15, and 45:15, showing in four out of the fourteen cases tabulated a great excess of orthoclase and strong affinities with the syenites. There are no exposures of anorthosite in the North Creek area, but the gabbros have come up through granite-porphyry, granite, quartz-syenite, and Grenville gneisses. If now we imagine a quartz-orthoclase Grenville gneiss caught up in a lime-rich, anorthosite magma and impregnated with the latter, a richly garnetiferous rock, with enlarged proportions of bisilicates might easily result. Even an aggregate not appreciably different from a garnetiferous member of the syenite series is possible. An origin of this sort for the basic syenitic masses which have been now several times encountered and which have been extremely difficult to classify, is deserving of very serious consideration.

The Garnet "reaction-rims" of the anorthosites. Since the time of Professor Leeds's studies upon the anorthosites the presence in them of rims of garnet surrounding the pyroxene and titaniferous magnetite has been a matter of record and knowledge. In the summer of 1914 the writer collected some exceptionally good material from a large boulder on the Chapel Pond road from the Keene valley to the valley of the Schroon river. Fortunately in the fall of 1914, Max Roesler, who had had some years of experience with the contact zones between intrusive rocks and limestones in Arizona, was studying with the writer at Columbia University, and undertook the investigation of the reaction-rims. Mr Roesler in the latter half of the university year became instructor in the Sheffield Scientific School at Yale University and completed his paper at the latter institution, where he had the valuable advice and suggestions of Professor Pirsson and the aid of Dr Walter F. Bradley in the chemical analysis. The results are here introduced as a contribution on one feature of the anorthosites which is of much petrographic interest. Coming after the recent studies of Prof. W. J. Miller on similar developments in the gabbros of the North Creek quadrangle, Mr Roesler's paper carries the subject a step further. For the contribution the writer takes pleasure in expressing his indebtedness.

SOME GARNET REACTION-RIMS IN ANORTHOSITE

BY MAX ROESLER

The hand specimens show irregular masses, of rudely lenticular shape, of brownish green pyroxene with associated magnetite, or else single pyroxene crystals, surrounded by rims of dark-red garnets with associated quartz. These garnets are very small and no individual crystal has been found that has a diameter greater than one millimeter. The ground mass in which these lenses and rims lie is a typical granulated anorthosite such as is common in the Adirondacks and as has been described by F. D. Adams [1] from the areas in Quebec. That is, it is light colored, granular, with occasional individuals of larger size that retain the blue-gray coloring of the fresh labradorite. This description applies to all the fragments except one, in which there is in the ground mass a very considerable amount of quartz in scattered crystals. For reasons which will appear later, and for the sake of distinguishing it from the ordinary anorthosite, this specimen will be spoken of as the aplitic anorthosite.

Thin sections were made of the various parts of several of the specimens, and their examination gives the following results.

The ground mass of the ordinary anorthosite is composed of plagioclase, granular, irregular in outline, twinned as a rule with the twinning lamellae often bent. In some of the grains of plagioclase there are inclusions of a clear material in a poikilitic arrangement and of lower index of refraction than the plagioclase. The inclusions are probably orthoclase. The plagioclase, judged by the extinction angles, is very close to labradorite, more often varying toward the more acid than toward the more basic varieties. There are occasional grains of orthoclase in one of the sections. As a rule they are limited to the inclusions in the labradorite. Plate 16 A illustrates these inclusions of orthoclase in the labradorite.

The section made of the ground mass of the "aplitic" anorthosite showed the following: Quartz in large grains, badly strained, but with very little evidence of granulation. Orthoclase in large grains, also badly strained, but not granulated. Microcline, several grains. Neither the quartz nor the feldspar shows good crystal outlines. Labradorite in a few small scattered and broken grains. These plagioclase grains show at times a graphic intergrowth with quartz. In one case the quartz within the plagioclase showed the same orientation as the quartz in interstices between the plagioclase grain

[1] Geol. Survey of Canada, Annual Rep't, v. 8, pt. J, p. 107–10.

and the surrounding grains. Occasional small grains of a micrographic intergrowth of quartz and orthoclase. Some of the orthoclase shows a microperthitic structure.

In this connection there was studied, thanks to Professor Pirsson, a thin section of the contact of an aplite dike in an anorthosite from Grand Discharge, Saguenay, Quebec. This aplite differs from the above only in that the quartz is less abundant and in smaller grains relative to the orthoclase and microcline. Also, there is no microperthite, and the orthoclase shows a tendency toward idiomorphism.

The garnet rims themselves show no variation in any of the thin sections of these specimens. They are entirely composed of pink garnet, rarely showing good crystal faces, and no anomalies. They are intergrown with and include grains of clear unstrained quartz. The quartz and garnet together form almost complete envelops about ferromagnesian cores. Their relations are illustrated in plate 16B. A more comprehensive illustration showing both the labradorite on the one side and the pyroxene on the other is given in plate 17A.

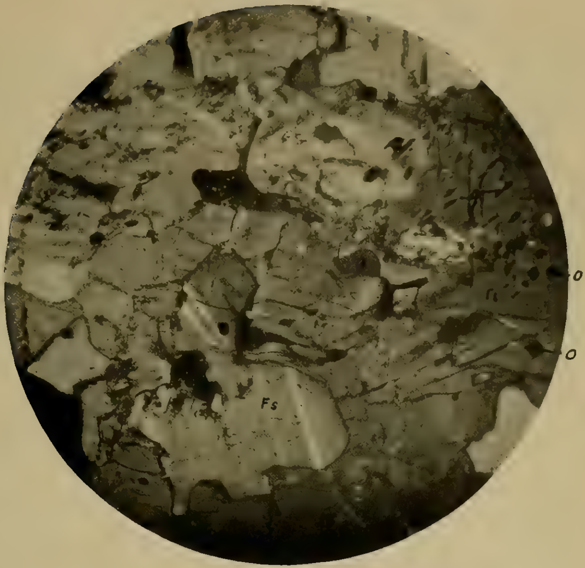
The thin sections of the core within the rims show that it is composed almost entirely of pyroxenes. These pyroxenes are pale green in transmitted light and show pleochroism either from pale green to pink or pale green to a very slightly darker green. Further examination shows that the pyroxene with the pleochroism to pink is orthorhombic and answers to the description of hypersthene. The other pyroxene is monoclinic and appears to be a variant of augite. As the extinction angle is uniformly high it would seem that the pleochroism is due to the presence of a ferrous iron (hedenbergite) molecule, rather than of a soda (aegirite) molecule. Both pyroxenes show in places good crystal faces.

As accessory minerals in these pyroxenic cores, there are magnetite, a small amount of alteration products: epidote, calcite, uralite, and more or less interstitial, clear quartz.

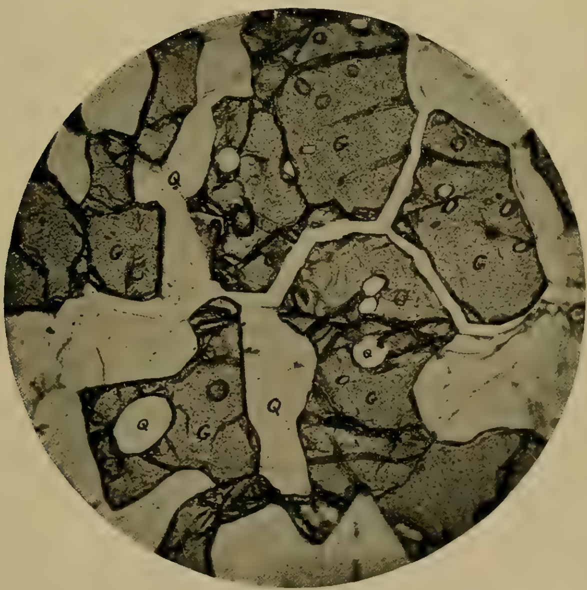
Plate 17B is a photograph of part of a section cut from what appeared in the hand specimen to be a single crystal. It shows an intergrowth of the hypersthene and the augite. The light-colored areas over the entire photograph are augite, the dark-colored areas hypersthene, and the black grains magnetite.

It is of interest to compare these relations with the descriptions of similar ones given by F. Zirkel in his paper on "Urausscheidungen in rheinischen Basalten," (Segregations in basalts of the Rhine), page 34. He says: "Extraordinarily clear are the inter-

Plate 16

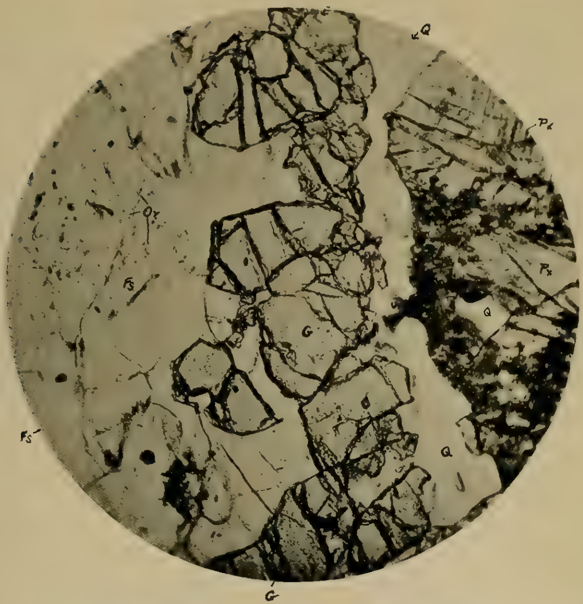


A. Microperthitic intergrowths of orthoclase (O) in plagioclase (Fs). Quartz is labeled (Q). Crossed nicols, actual field 0.08 inch or 2.0 mm.



B. Garnet and quartz in the reaction rims. Q is quartz; G is garnet. White light, actual field 0.05 inch or 1.3 mm.

Plate 17



A. Garnet reaction rim showing the labradorite (Fs) with included orthoclase (Or), on the left; garnet (G) in the center, succeeded by quartz (Q) and pyroxene (Px) on the right. White light, actual field 0.08 inch or 2.0 mm.

B. Section of intergrowths of pyroxene, var. hedenbergite (Px), and hypersthene (Hy). Magnetite is (Mg). Crossed nicols, actual field 0.08 inch or 2.0 mm.

growths, repeatedly observed, of fine lamellae of monoclinic augite in these enstatites." Plate 18A is a photograph of an area of pyroxene, in the ground mass of anorthosite, which is not surrounded by garnets, but which shows a good development of a green amphibole thought to be uralite.

From one of the specimens with a favorable reaction rim, enough of the garnet was sorted out for the making of duplicate chemical analyses which give the following as an average:

SiO_2	40.11
Al_2O_3	22.90
Fe_2O_3	.60
FeO	25.31
MgO	4.46
CaO	6.19
MnO	trace
TiO_2	none
	99.57

An attempt to recast this analysis indicates that the elimination of quartz and feldspar was not complete. It shows, however, the presence in the garnet of the almandite, pyrope and grossularite molecules. Their ratio to one another is probably about

3 parts almandite, $3FeO, Al_2O_3, 3SiO_2$
1 part pyrope — $3MgO, Al_2O_3, 3SiO_2$
1 part grossularite $3CaO, Al\ O_3, 3SiO_2$

The amount of grossularite is open to question since some of the calcium may have come from labradorite.

A summary of the facts shown by megascopic, microscopic and chemical examination follows:

There are in this rock aggregates of pyroxene made up mostly of a variety of augite and partly of hypersthene with accessory magnetite and interstitial quartz. This quartz shows no strain shadows. These aggregates may or may not be surrounded by garnet rims. Where the garnet rims are lacking, there is a greater development of uralite than when they are present.

The garnet rims are composed of garnets containing the almandite, pyrope and grossularite molecules, and of unstrained quartz grains. The ground mass is as a rule a normal granulated anorthosite. In one case it is an aplite showing strain and containing grains of broken labradorite. Unfortunately, the hand specimen is not sufficiently large to show the relationship between the aplite and anorthosite, and this relationship must be left to inference on a very meager basis of fact.

In connection with this work a number of thin sections of other garnet occurrences in the Adirondacks were studied and, in part, photographed. These sections have been supplied by Professor Kemp and have been in part previously described by him. Plate 18B illustrates a reaction rim in the basic gabbros. It introduces biotite. Plate 19 contains two cases of garnet growths from the contact zones produced from limestones by the intrusives. The upper illustration (A) is taken from a slide from the same exposure as is illustrated in plate 8. Narrow zones of garnet have developed between the pyroxene (hedenbergite) and scapolite. The lower illustration (B) brings out a very peculiar interfingering or parallel growth of pyroxene and garnet, from the Weston mine. Nothing in the nature of a rim is presented by the slide, but rather the intimate relations which the production of pyroxene in a limestone contact bears to that of garnet. Similar intergrowths of garnet in the multiple-twinned plagioclase, the garnet taking the place of alternate lamellae have been described by Professor Kemp.[1] Plate 10B illustrates the formation and relations of garnet in a gneiss of the general composition of the syenites and believed to belong to them. While the feldspar is predominantly orthoclase, acidic plagioclase also enters, and probably contributed to the garnet.

Discussion. Upon the basis of the evidence presented and upon the observations of others a satisfactory explanation of the reaction rims must be based. Search through the literature revealed the following. The earliest reference to a case at all similar is given by A. Lacroix in a paper on "Gneiss à Pyroxene et à wernérite de Bretagne," printed in the Bulletin de la Sociétè Minéralogique de France, v. 12, 1889, p. 85–365. In giving a description of some rims around olivine he refers to an article by Törnebohm on some rims about olivine in the gabbros of Wermland.[2]

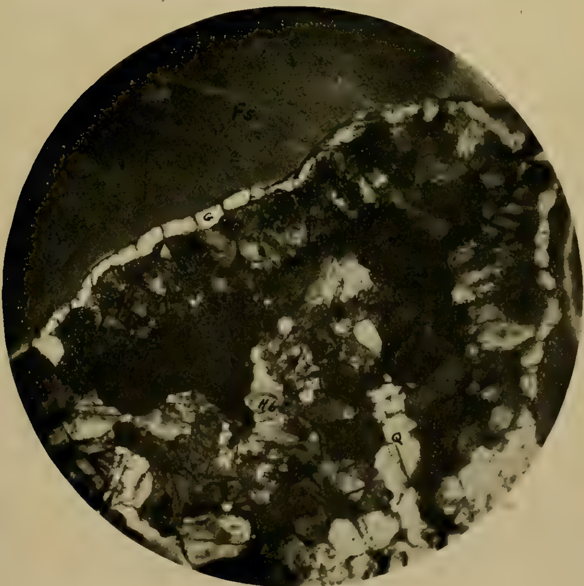
The original paper of Törnebohm's was not available but, according to the citation in Lacroix, it dealt with rims of other minerals than garnet. Lacroix himself describes, among others, some rims of garnet, between labradorite and amphibole which surround pyroxene around biotite around a core of magnetite. These rims occur in a gabbro at Odegarden, which is in contact with an amphibole gneiss. The only comment made in regard to origin of the rims is "Dans le roches que nous étudions, il semble difficile d'admettre que le grenat soit exclusivement formé au contact du gneiss amphibolique."

[1] Kemp, J. F., "Gabbros on the Western Shore of Lake Champlain." Bul. Geol. Soc. Am., 1895, 5:219–20.

[2] Köngl. Svenska Vetensk. Akad. Fordhandl, i. Stockholm, 1877.

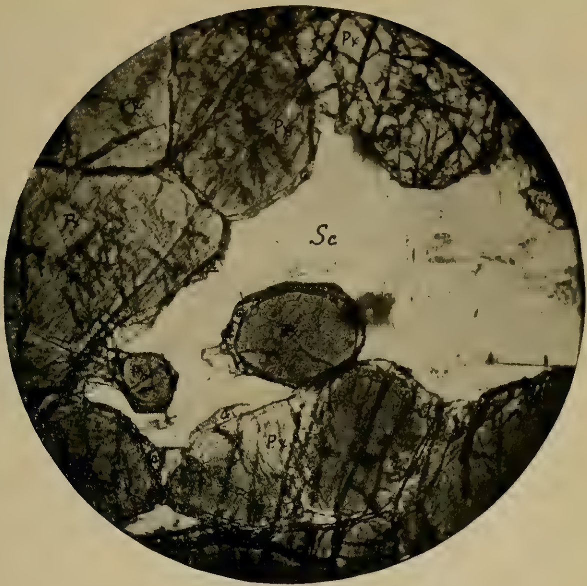
Plate 18

A. Pyroxene (Px) and hypersthene (Hy) in contact with labradorite (Fs) and with no reaction-rim of garnet, but with associated uralitic hornblende (Hb). Crossed nicols, actual field 0.08 inch or 2.0 mm.

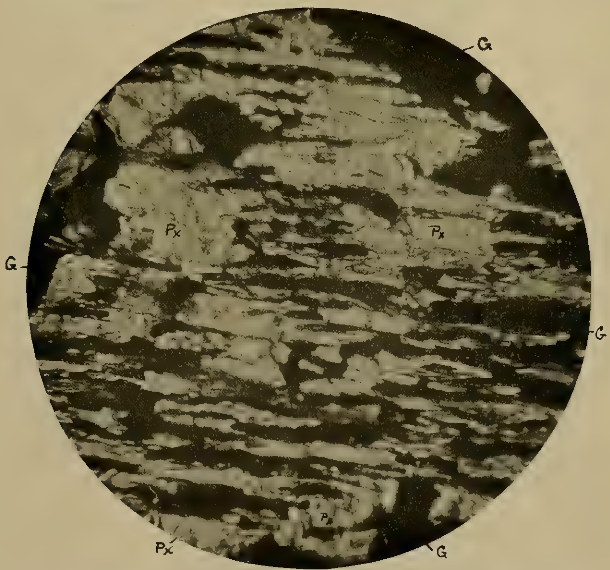


B. Narrow reaction-rim of garnet (G) between labradorite (Fs), clouded by innumerable minute inclusions, and an inner core of biotite (Bi), hornblende (Hb), magnetite (black) and quartz (Q). White light, actual field 0.08 inch or 2.0 mm.

Plate 19



A. Narrow zones of garnet (G) between pyroxene, var. hedenbergite (Px), and scapolite (Sc). From the same locality as plate 8. White light, actual field 0.08 or 2.0 mm.



B. Intergrowth of garnet, the dark mineral (G) with pyroxene, var. hedenbergite (Px), the light mineral. Contact zone, Weston mine. Crossed nicols. Actual field 0.08 inch or 2.0 mm.

(Opus cit., p. 236) "In the rocks which we are studying, it seems difficult to admit that the garnet should be only formed along the contact with the hornblende gneiss."

The first mention of garnet rims in the Adirondacks that has come to the writer's notice is in the paper by A. R. Leeds, "Notes upon the Lithology of the Adirondacks.[1]"

In describing a specimen he says, "Garnet is not unfrequently disposed as a red border around the greenish masses of diallage, along the bounding surfaces between it and the labradorite." No theory of their formation is mentioned.

Since Professor Leeds's paper, garnet rims from the Adirondacks have been described by J. F. Kemp[2] and W. J. Miller[3] in various articles.

This list does not claim to be a complete one, but gives those articles which have been of particular interest to the writer. J. F. Kemp, in the article on the titaniferous iron ores, speaks of an occurrence in gabbro which "has been somewhat squeezed, so that secondary garnets have been developed in quantity." W. J. Miller (op. cit., p. 30 and 31) describes several rims, some of garnet, others lacking the garnet and composed entirely of other ferromagnesian minerals. He designates them as "reaction or corrosion rims" and also says that "Garnet is almost invariably in contact with feldspar which suggests the partial formation, at least, of the garnet from feldspar."

Another occurrence of garnet that must be mentioned in this connection is that described by F. Zirkel.[4] In this case the garnet occurs not as rims but as aggregates in a basalt, and has been regarded as primary.

The study of the specimens and the literature suggested four possible modes of formation for the garnet rims: (1) that these lenses represented stoped-in fragments of the rock invaded by the anorthosite and metamorphosed to pyroxene-garnet masses; (2) that the garnets were primary and the zonal arrangement due to the order of crystallization; (3) that in this particular case there had been an addition of silica due to an aplitic invasion; (4) that the garnets

[1] Thirtieth Ann. Rep't, N. Y. State Mus., 1876.

[2] J. F. Kemp, "Gabbros on the Western Shore of Lake Champlain," Bul. Geol. Soc. America, v. 5, p. 217–21, 1894.

J. F. Kemp, "The Titaniferous Iron Ores of the Adirondacks," pt 3, 19th Ann. Rep't, U. S. Geol. Surv., 1897–98.

[3] W. J. Miller, "Geology of the North Creek Quadrangle, Warren County, New York." N. Y. State Mus. Bul. 170, 1914.

[4] "Über Urausscheidungen in Rheinischen Basalten," Leipzig, 1903.

were the result of reaction between the ferromagnesian core and the feldspathic ground mass.

The first theory made a peculiarly strong appeal to the writer since, to one familiar with the geology of copper mines, garnet connotes contact metamorphism. In favor of this theory is the fact that the Adirondack anorthosites do cut such sediments as might give inclusions that would alter to garnet rocks. Also the boundary between the garnet surrounded masses of pyroxene and the ground mass is at times very sharp. But the evidence against this theory is too strong. The pyroxenes in those aggregates surrounded by garnet differ in no way from pyroxenes in the rest of the rock and are apparently endogenous. The garnets are not limited absolutely to the rims about the pyroxene; an occasional individual is found out in the feldspar, and also within the pyroxene mass. Furthermore, if these rims and lenses had been formed by contact metamorphic action on stoped-in fragments, they must have been produced previous to the later dynamic metamorphism which granulated the mass of the rock. In the hand specimen they show no effect of such metamorphism, the lenticular masses lying in the rock without any tendency toward parallelism. The slides show no granulation of the pyroxenes. There is then the possibility that the fragments represent a stoped-in pyroxenite about which the garnets have formed later. This seems rather unnecessary when the same pyroxenes are found undoubtedly endogenous in the normal rock.

The next theory is that these entire lenses, both garnet and pyroxene, represent primary segregations like those described by F. Zirkel in basalts (op. cit.). This does not require that we ascribe to a gabbroic magma, contact effects that are usually associated with more acid intrusives. It is, moreover, an explanation which accounts for the pyroxenic aggregates and the garnet at the same time. The same objection as to lack of granulation in these masses formed prior to the dynamic metamorphism holds against this theory as applied to the garnet rims. But if it can be shown that the garnet rims are the expression of that dynamic metamorphism around the pyroxenes, there is no reason why the pyroxenes may not represent such segregations.

Another objection to regarding the entire lense, rim and all, as an original segregation, is the comparatively large amount of quartz present. This quartz is entirely lacking in strain shadows and has all the appearance of being contemporaneous with the garnet.

The theory that the garnet formation is due to silica from an aplitic invasion hinges upon one specimen. It is rather difficult to offer evidence either for or against this case. The aplite is very badly strained and so shows that it has been subject to some dynamic metamorphism. It includes some small grains of basic plagioclase, but whether these are part of the already granulated anorthosite or have been included prior to granulation is not definitely shown. The writer is of the opinion that the aplite invaded the rock after most of the granulation had taken place, but this opinion is based on very slight evidence and is not a conviction. Since the aplite has been observed in only one specimen it can certainly not be regarded as playing any important rôle in the majority of cases and may be disregarded.

There remains the explanation that the garnet rims are due to reaction between feldspars and ferromagnesian minerals. This process has been suggested by J. F. Kemp and accepted by later observers, but so far as the writer knows there has been no very complete discussion of it. Applied to the specimens in hand, it seems to meet all the facts. The garnets lie between a basic plagioclase ground mass and an aggregate of augite and hypersthene. They are composed of the lime, the magnesia, and the ferrous-iron-bearing garnet molecules as shown by analysis. The hypersthene could supply some of the magnesia, ferrous iron and silica. The augite could supply more of the ferrous iron and magnesia, some of the lime and some of the alumina and silica. The ferric iron of the augite could have gone into the formation of some of the magnetite. From the basic plagioclase the anorthite molecules could add more lime, alumina and silica. The slides show an excessive development of silica, contemporaneous with the garnet and some of the magnetite. This also accords with the conditions. To take the simplest case; hypersthene $(Mg,Fe)SiO_3$ reacting with anorthite $Ca\,Al_2Si_2O_8$, to form a garnet $Ca\,Mg\,Fe\,Al_2(SiO_4)_3$. This would require two hypersthene molecules and one anorthite and could be written: $MgO.FeO(SiO_2)_2 + CaO.Al_2O_3(SiO_2)_2 = CaO.MgO.FeO.Al_2O_3(SiO_2)_3 + SiO_2$. The presence of quartz may then be regarded as a partial confirmation of the reaction. The greatest difficulty is to account for the albite molecule which must have been associated with the anorthite in the plagioclase. In the thin sections certain small grains and inclusions were determined as doubtful orthoclase or microline. It is quite possible that these are anorthoclase, and might account for some of the soda. If this is admitted, and the lack of a definite accounting for the soda not regarded as an insuperable obstacle, the possibility that the garnets represent a reaction between feldspar and the pyroxenes has been established.

The cause for the reaction seems to lie in the dynamic metamorphism. F. D. Adams, in the work cited above, mentions the fact that the pyroxenes in the granulated anorthosites of the Morin area were also granulated. The pyroxene in the specimens under discussion show no such granulation. It seems to the writer that this indicates that the specimens come from an anorthosite that was granulated under conditions differing from those that obtained in the Morin area. Possibly a greater development of heat permitted a fusion and recrystallization around the edges of the pyroxenic aggregates. There may have been a greater amount of water or of other mineralizers which permitted fusion at a lower temperature in these pyroxenes. In fact, tests for combined water show 0.56 per cent in the pyroxene and 0.34 per cent in the granulated anorthosite away from the rim. Whatever the cause may be, any explanation which does not admit that these garnet rims are the expression of the dynamic metamorphism that caused granulation in the rest of the rock, must either show the entire lenses to have been introduced later than the metamorphism, or else give some other accounting for the lack of granulation. If, however, these rims are admitted to be the expression of the dynamic metamorphism, there is no further objection to regarding the pyroxenic aggregates as original segregations.

There remains the fact that certain small areas of pyroxene in the specimens are not surrounded by garnet. These areas are made up of very small crystals and show a great development of amphibole which appears to be secondary. Plate 18A shows this. In this case the amphibole formation represents the metamorphism.

After regarding the various views suggested, the one that seems most tenable is that the garnet rims represent a reaction between pyroxene and feldspar induced by the same causes that brought about the granulation of the ground mass. This conception has the advantage of being widely applicable, as its requirements are very few: a ferromagnesian mineral in contact with a feldspar, and the proper degree of heat and pressure. It certainly seems to the writer to fit almost all the cases that he has studied or whose description he has read.

COMMENTS BY J. F. KEMP

It will be noted that in one of the specimens studied by Mr Roesler, minerals suggesting an aplitic addition to the anorthosite from an outside source were observed. Some apparent corroboration of the suggestion was gained from a specimen of Canadian anorthosite with an aplite dike, in the collection of Professor Pirsson. Yet all the specimens furnished Mr Roesler by the writer came from one large boulder of otherwise normal anorthosite, and no intrusive dike of any sort appeared in it nor have we yet observed aplite intrusive in the anorthosites.[1] Pegmatites of granitic composition are known in a few cases, but nothing as yet that would be described as aplite. The aplitic minerals would appear to be necessarily due to some reaction in the anorthosite itself. With regard to the formation of the reaction rims it may be further noted that they appear around large and thoroughly uncrushed crystals of labradorite, caught in the great masses of titaniferous magnetite on Lake Sanford, in the neighboring Santanoni quadrangle; and that they are observable sometimes in the basic gabbros which are still not appreciably granulated. They may in instances, at least, be due to some magmatic corrosion of older formed minerals, and in the closing stages of crystallization. Nevertheless the garnets in the thoroughly mashed anorthosite would seem to be the results of some reaction of pyroxene and labradorite, incident to the dynamic metamorphism because they are sometimes from half an inch to an inch in diameter, not apparently granulated, and looking in the crushed anorthosite much like a red knot in a pine board.

Peculiar gabbro. In one of the earlier season's work a ledge was observed which had been blasted shortly before in highway improvement and which proved to be a very curious departure from the normal anorthosite. The locality is on the old road from Keene valley to the Ausable Club (Beede on the map), and within one-fourth of a mile of the forks. In recent years a new road has been built farther west. The rock impresses one as a gabbro-porphyry. Large, rectangular pale-green crystals of labradorite are set in a blackish green finer grained matrix. Under the microscope the dark-green ground mass is resolved into granular, green augite. Some augites are larger than others, but as a whole granulation is

[1] Since the above was written H. L. Alling has found a narrow aplite dike several inches in width cutting an anorthosite boulder on East hill, northeast corner of the quadrangle. Under the microscope the essential minerals are quartz, soda-microcline and microcline-microperthite. The accessory minerals are magnetite, uralite, biotite and diopside. There is considerable garnet in the rock which is regarded as resulting from metamorphic action.

pronounced. There are rather coarse masses of titaniferous magnetite, altering to leucoxene. This peculiar type of rock was noted in the Elizabethtown quadrangle near New pond (Museum Bulletin 138, p. 43) and has also been observed just north of the edge of the Mount Marcy quadrangle, on the east bank of the Ausable river above Keene Center. The rock under pressure and shearing would readily change into horneblende gneiss with parallel bands of feldspar and horneblende. It is undoubtedly the parent rock of some puzzling gneisses. Exposures have proved so limited that observations are insufficient to prove whether it is a separate intrusive mass or a peculiar phase of pyroxenic anorthosite. Its affinities are with the anorthosites.

4

THE PRECAMBRIAN INTRUSIVES, CONCLUDED

The Syenites. The syenites are developed in the northern edge of the sheet. They present the usual dark green gneissoid rock, now become widely familiar in the Adirondack area. Under the microscope microperthite is the chief component. The spindles of albite which give the feldspar the microperthitic character are sometimes set in orthoclase, sometimes in microcline. Plagioclase appears in a subordinate capacity in the typical cases, but in the syenite of Pitchoff mountain on the borders with the anorthosite, it sometimes becomes quite prominent. The syenite has acquired or developed blue labradorite crystals and one does not know with which series of rocks, syenites or anorthosites, to place the specimens. The most typical dark silicate is emerald green augite, presumably of a soda-bearing variety. Brown or green hornblende is also present, and at times hypersthene. Stray bits of magnetite and the small accessories, zircon and apatite, make up the balance. The characteristic syenite has been collected on a shoulder of Scott's Cobble. It is illustrated in plate 20A. Elsewhere in this hill it shades into siliceous varieties with much quartz, practically a granite. These variable characters have, however, not infrequently been observed in the extended exposures of syenite elsewhere.

No analyses have been prepared of the syenites within the Mount Marcy quadrangle but a number are given of specimens in Bulletin 138, page 45, and the rocks are treated at length by Professor Cushing in Bulletin 115.

Pegmatite. On the western shoulder of the summit of Mount Porter, C. H. Fulton, the writer's assistant in 1897, noted in the anorthosites a pegmatite vein mainly containing microcline and quartz. In the summer of 1914 the writer and H. L. Alling were on the eastern shoulder of Mount Porter and were impressed with a small series of pegmatites containing microcline as the feldspar. They filled crevices in the anorthosite. The association is a peculiar one in a rock so low in potash as the anorthosite. We know of no other intrusive rock near, which might have supplied the pegmatite. A parallel is mentioned in Bulletin 138 where orthoclase pegmatites in association with the basic gabbro are mentioned from the Elizabethtown-Port Henry quadrangle. Prof. W. J. Miller describes the same peculiar association in the North Creek quadrangle in Bulletin 170, page 38. A pegmatite dike also appears east of the included limestone at the Cascade lakes.

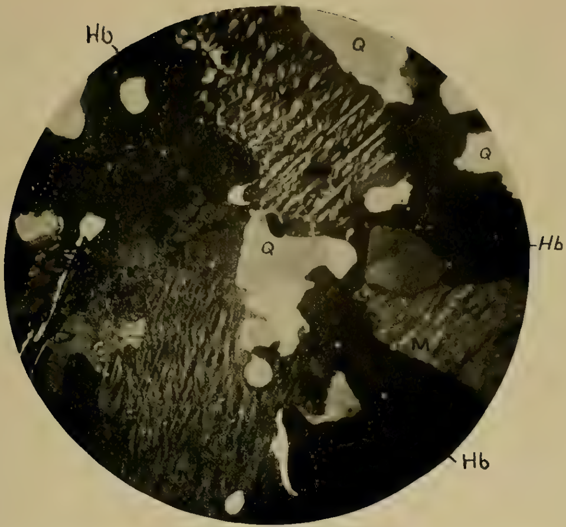
Granite. While rocks of granitic composition have been observed they seem to be so closely connected with the syenite series as to be mapped with them. On Scott's Cobble along the northwestern edge of the sheet this is true. There are, however, in the bed of the East branch in the Grenville area on the northern border, some very narrow dikes of pink granitic rock which traverse the old Grenville sediments and merely deserve passing mention. There is also a very small exposure of red granite on the east pass of Baxter mountain, where the two branching trap dikes are mapped. The granites do not constitute a sufficiently large member in the local geology to receive a special color on the map.

Gabbro-syenite of the basic gabbro series. In the summers of 1888, 1889 and 1890 the writer was in the field accompanied by V. F. Marsters studying the trap dikes of the Champlain valley and neighboring mountains.[1] Having read in Prof. Ebenezer Emmons's Report on the Second District, page 215, of the great trap dike at Avalanche lake,[2] we made a trip into the mountains to visit it. As the dike lies in a steep-walled gorge between the main mass of Mount Colden on the south and its northern shoulder, sometimes called Avalanche mountain, it impressed the writer as a mass of sheared and dynamically metamorphosed rock in a faulted zone. It was therefore described as "The great shear zone near Avalanche lake in the Adirondacks," in the American Journal of Science, August 1892, pages 109–14. The contrasted mineralogy of the dike when compared with the anorthosite walls was thought to be due to crushing and recrystallization. The decided abundance of garnet, which was considered a metamorphic mineral, and the finely crystalline, granular nature of the rock gave some color to the view. Mineralogically the dike consisted of predominant, irregular and rather fine-grained hypersthene, augite, garnet, hornblende and magnetite, with less abundant plagioclase and orthoclase, all showing crushing. The neighboring walls are coarsely crystalline anorthosite. At this time the writer was familiar with the diabase dikes of the mountains and with the trachytic and rare basaltic rock types in the dikes of the

[1] The results found publication as Bulletin 107, of the U. S. Geological Survey, 1893.

[2] Even earlier mention of the dike is made by W. C. Redfield in "Some Account of Two Visits to the Mountains of Essex Co., N. Y., 1836–37," Amer. Jour. of Science, 1st series, 33:301. On one of these expeditions, both of which were undertaken to examine the iron ores of Lake Sanford, James Hall accompanied Mr Redfield. Professor Emmons was with him on the other. Interest in the iron ores was very keen at the time. Professor Emmons describes the dike also in the Second Annual Report, N. Y. State Survey, 1838, p. 225, Atlas, pl. 4.

Plate 20



A. Syenite from Scotts Cobble, containing microperthite (M), brown hornblende (Hb), and quartz (Q). Crossed nicols, actual field 0.08 inch or 2.0 mm.

B. Plumose border of bostonite dike on the left, against Grenville gneiss on the right. Crossed nicols, actual field 0.08 inch or 2.0 mm.

Champlain valley, but the basic gabbros of the mountains had not yet been recognized. To this latter group the dike undoubtedly belongs. Prof. Ebenezer Emmons was entirely correct in regarding it as igneous and in calling it a trap dike. It does, however, exhibit effects of crushing and perhaps some recrystallization but it is too basic and too rich in iron and magnesium to have been derived from anorthosite. Undoubtedly it entered as a large basic dike. When subsequently exposed at the surface its relatively easy weathering produced the gorge. The dike strikes N. 50–60° W. Near the lake it is 75 feet wide. Its dip is vertical. Professor Emmons states that the dike can be traced up Mount MacIntyre across the lake. The dike is peculiar in the amount of orthoclase which it contains. There is enough to make one hesitate whether to class it with the basic syenites or basic gabbros. This difficulty has been avoided by calling it gabbro-syenite. No statistical measurements have been made, but the rock is obviously much like the gabbros rich in orthoclase such as are described by Prof. W. J. Miller in the North Creek area (Bulletin 170, page 29) and as mentioned on a previous page of the present contribution.

In 1895 in going from Avalanche Lodge to Lake Sanford by way of the Indian pass the writer noted another dike of this same character, nearly 3 miles to the northwest of Avalanche dike and with a parallel strike and dip. As nearly as could be determined the new exposure is just where the trail southwest from Clear lake leaves the Mount Marcy quadrangle. If the location is correct, the dike last discovered is somewhat north of the line of the strike of the Avalanche dike; but its course is in the same direction. Apparently two intrusive masses entered the anorthosite along similar general lines of weakness.

Basaltic dikes. The last member of the hard rock formations consists of the series of basaltic dikes which are so widespread in the eastern Adirondacks. From fifteen to twenty have been discovered in the Mount Marcy quadrangle, but there are undoubtedly others. Almost without exception the observed dikes strike northeast and southwest parallel with one set of the large structural lines of the mountains. In most cases the dikes have found their way upward along these lines of weakness. They are of later introduction than the metamorphism of the ancient crystallines and may have entered long after the Precambrian so far as any local evidence to the contrary is available. The acute observations of Professor Cushing[1] in

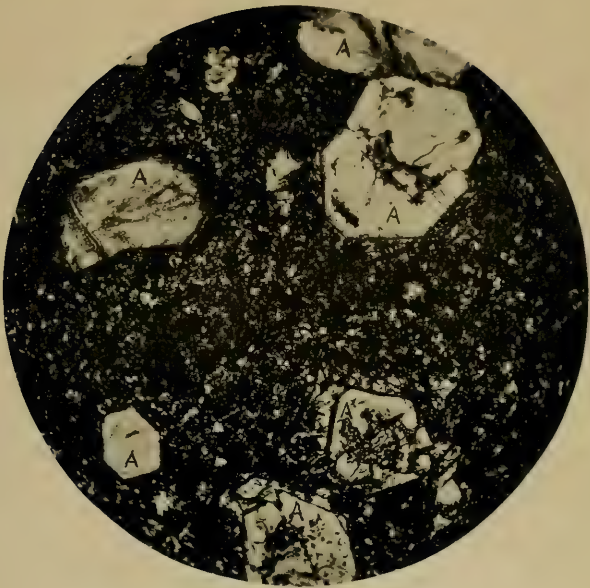
[1] H. P. Cushing, "On the Existence of Precambrian and Postordovician Trap Dikes in the Adirondacks." Trans. N. Y. Acad. of Sci., 15:248–52, 1896.

Clinton county brought out as early as 1896 the existence of two series of basic intrusions, whereas before this time no such contrasted grouping had prevailed. His field work along the edge of the Potsdam sandstone which rested on the older gneiss revealed many dikes of diabasic character in the gneiss, but none passing upward into the Potsdam. On the other hand we knew of trachytic (or bostonite) dikes and rare basaltic types (camptonite and others) which cut both ancient crystallines and Paleozoic strata up through the Utica slate.

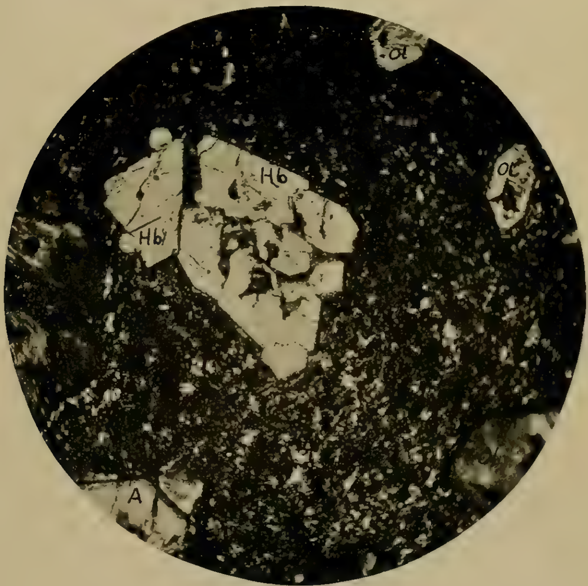
The basaltic dikes in the Mount Marcy quadrangle are dense, finely crystalline rocks whose exact mineralogy and textures can be determined only with the microscope. Slides have not been prepared of every dike met and one can only say that to the unaided eye they seem in the cases from which no slides have been studied to be identical with the Precambrian diabases. On the other hand microscopic examination of a dike in the Johns Brook valley, just below the entrance of Ore Bed brook, shows it to be related to the camptonites. It consists of an interlacing mass of minute augite prisms about 0.05 mm broad by 0.5 mm long with many bits of magnetite in a matrix apparently plagioclase. The twinning of the plagioclase is often apparent, but is not always pronounced. There may be some other minerals, such as analcite, involved. The texture is excessively fine and with high powers the identity of the minerals is difficult to establish. Of much the same general character is the basaltic dike, 5 feet wide, shown in figure 1 and illustrated in plate 21. The phenocrysts are well bounded and usually zonal augites, brown, basaltic hornblendes and olivine. The ground mass is chiefly an interlaced aggregate of minute prisms of augite and hornblende, with some lighter colored minerals, presumably plagioclase and analcite or some similar alkaline-alumina silicate. With such small components it is difficult to get satisfactory tests in a naturally opaque rock. Magnetite in small irregular bits does not fail.

Clearly these dikes, so far as microscopically studied, are camptonites and are related to the post-Ordovician dikes of the Champlain valley. This is a peculiar feature and may stamp them as a local outbreak of the same magma far in the mountains. The discovery of a fragment of a bostonite dike, although not in place, yet penetrating the rock regarded as Grenville gneiss partly digested in anorthosite, and near the headwaters of Johns brook, is another peculiar and corroborative observation. The camptonites and bostonites are associated in the Champlain valley. There is every reason

Plate 21



A. Camptonite dike from the bed of the Ausable river, north edge of area. Augite (A). The groundmass is a fine aggregate of brown hornblende prisms and plagioclase, probably with analcite. White light, actual field 0.08 inch or 2.0 mm.



B. The same rock as A, but showing brown, basaltic hornblende (Hb), olivine (Ol) and augite (A). White light, actual field 0.08 inch or 2.0 mm.

to think that the bostonite dike at the head of Johns brook came from some ledge in the immediate neighborhood.

Prof. Albert B. Leeds, in connection with the analyses of anorthosite and its constituent minerals earlier referred to, also made an analysis of one of the basaltic dikes, named by him dolerite, and stated to be intrusive in the Norian rocks (that is, anorthosites, as we now use the term). Doctor Leeds also examined a thin section and has given us the following microscopic description (pages 28–29 of the separate). From it we can do little more than conclude that the specimen came from a very dense, and presumably narrow dike, and that it probably was a camptonite:

21 Section of the dolerite, whose analysis has been previously given. A large portion of the transparent base of this rock could not be definitely referred by its optical characters to plagioclase. It presents a considerable admixture of quartz. The dark color of the section and rock is due in part to the magnetite and menaccanite, but in still greater degree to very minute light to dark green and yellowish-red masses. The former are probably pyroxene, the latter, which are by far the most abundant, hornblende.

Doctor Leeds unfortunately does not give the locality whence the specimen was obtained. The rock with its high CO_2 and H_2O was obviously not perfectly fresh, although some of the water may have been in analcite. All the water was in a soluble mineral, but it seems strange that some of the silica did not also go into solution. In so basic a rock, the quartz, if correctly determined, must have been secondary. In citing the analysis and its two associates the oxides have been rearranged somewhat, to conform with modern customs.

	Total	Soluble	Insoluble
SiO_2	43.41		43.41
TiO_2	0.35	0.367	
Al_2O_3	19.42	9.097	10.324
Fe_2O_3	5.72	4.553	1.169
FeO	6.69	6.693	
MgO	5.98	5.285	0.695
CaO	9.11	7.398	1.711
Na_2O	4.39	0.530	3.864
K_2O	0.47	0.323	0.144
CO_2	2.00	2.003	
H_2O	3.00	2.997	
	100.54	39.246	61.317
Sp. gr.	2.89		

If we attempt to recast the analysis we can not assign all the Na_2O to albite because then we will run short of SiO_2 for the anorthite, which must be in so basic a rock in even greater quantity than the albite. On the other hand, if we assume that the Na_2O is in analcite or nephelite in sufficient proportion to ease the difficulty just stated, we can not understand why these very soluble minerals did not go more largely into solution. Only by assuming some rather basic plagioclase and then assigning arbitrarily the soda to nephelite or analcite can a recasting be carried out and then the results in soluble and insoluble must be ignored. Recasting has therefore not been attempted.

Bostonite. In the locality in the Johns Brook valley below the junction with Ore Bed brook a loose piece or boulder was discovered which was partly the dark rock regarded as an included mass of Grenville gneiss, and partly a trachytic or bostonite dike. The dike is of dense, felsitic texture, of pale green color, and about 35 mm, or 1.4 inches, wide. A thin section of the two at their contact revealed a remarkable plumose arrangement of the orthoclase rods, as illustrated in plate 20 B. The border is 0.5 mm wide and is succeeded by the normal bostonite which is an interlacing mass of rods of orthoclase or perhaps anorthoclase. No dark silicates can be detected. The rods have an extinction closely if not invariably parallel with the elongation. The boulder is believed to have been derived from the ledges in the immediate vicinity. The bostonite dike is the first one met in the mountains south of the northern border. Dikes of this character are most frequently observed cutting the Paleozoic strata of the Champlain valley. Under the name of syenite-porphyry, however, dikes which cut the old crystalline rocks in Clinton county have been described both by A. S. Eakle [1] and H. P. Cushing.[2]

5

FAULTS, AREAL DISTRIBUTION OF FORMATIONS

Faults. In an area of predominant massive rocks such as the Mount Marcy quadrangle structure can not be worked out to any such degree as is possible in sedimentary and contrasted strata. Faults are the large structural features and yet they must often be a matter of inference from the precipitous topography. Sometimes, however, the crushed and decomposed rock can be seen. In the summer of 1910 a borrow pit for improving the highway on the west bank of the East branch of the Ausable river and just north of the edge of the quadrangle, revealed a zone of thoroughly crushed and kaolinized anorthosite, striking nearly parallel with the trend

[1] Eakle, A. S., Amer. Geol., July 1893, p. 34.
[2] Cushing, H. P., Bul. Geol. Soc. Am., 9:239–56, 1898.

of the Keene valley and evidently indicating a powerful fault. The crushed rock was still visible in 1914, although the exposure was not so fresh and clear. The fault seems to bear into the hill somewhat to the west of the valley as one goes north.

To the south of this exposed and visible fault the East branch of the Ausable is in a deep, rocky postglacial gorge as described and illustrated by H. L. Alling in subsequent pages. The river has a zigzag course because it uses sometimes east and west faulted and crushed zones, sometimes others north and south. The crushed zones can be detected at times in the hard gneisses, and one east and west one is occupied by a trap dike, 5 feet in width, which on the place exposed runs true with the stream. The stream turns to the north and follows the direction of a north and south crush which can be seen in the highway on the east bank where a strong fault breccia of gneiss is exposed. The locality is just in the edge of the sheet next the Lake Placid quadrangle on the north. The fault breccia consists of fragments of green, syenitic gneiss cemented by comminuted fragments stained by chlorite. The north and south lines of brecciation and crushing, we are justified in prolonging to the south in the depressions, less well exposed.

On the east side of the Keene valley along the highway whose extension formerly ran on the south side of Baxter mountain, and about a mile from the East branch of the Ausable river, is Beede's rotten stone quarry. On the north side of the road, sheeted, crushed and decomposed anorthosite is quarried and used for macadam with excellent results. The decomposed belt, as exposed, is nearly 100 feet broad and has knots of less altered rock in it. The strike of the sheeting is almost due east and west, referred to the true north, and dips 45° to 55° north. It would supply a line of weakness for the development of an east and west valley, such as the one on whose side it appears.

From the positive and well-exposed lines of east and west and north and south crushing, we are justified in inferring a series of faults with these strikes. We note, also, that their direction corresponds to some pronounced features of the relief, such as the Keene valley and the valley of Elk lake.

Study of the map will also bring out the fact that the crushed and decomposed exposure at Beede's rotten stone quarry is at the junction of the east and west fault-lines with one which comes to it in a southwest direction from the pass immediately southeast of Baxter mountain proper and which is prolonged farther to the southwest in the Johns Brook valley. The Johns Brook valley heads on the east side of the summit of Mount Marcy and when the line of the depression is followed to the southwest across the divide, it passes straightaway down the steep-sided depression of Skylight brook. The line is almost mathematically parallel with the great fault-valley of the Ausable lakes on the southeast and the fault-valley of the Cascade lakes on the northwest. The steep-sided depression which contains Avalanche lake, Lake Colden and the Flowed lands runs also parallel to it but is less extended. The same is true of the precipitous pass northwest of Pitchoff mountain. In the extreme southeastern corner of the quadrangle the valley of Niagara brook with the wonderful and precipitous escarpment of Niagara mountain, serves to further emphasize these great northeast and southwest lines of faulting, which are the chief structural features of the quadrangle.

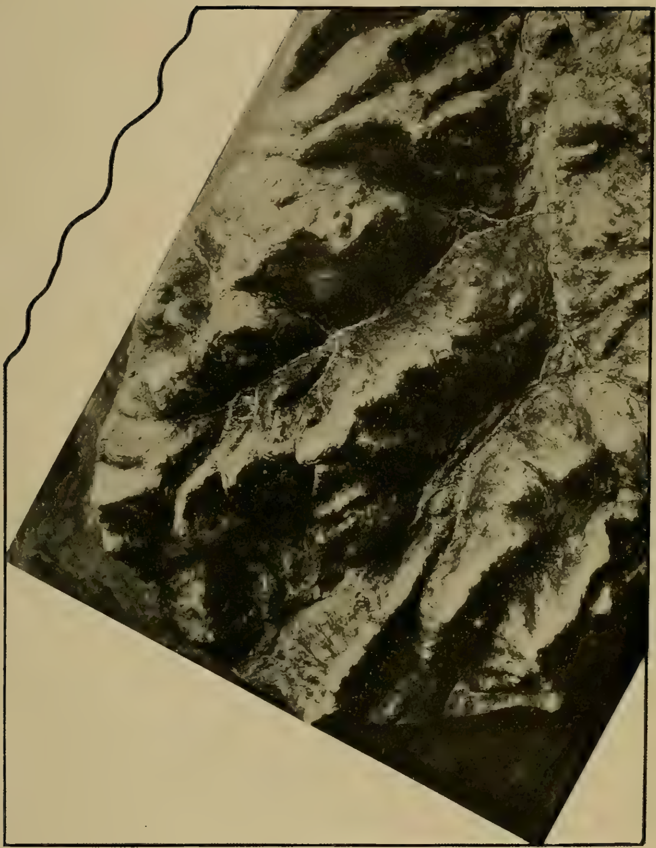
The lines of faulting are not always single. In the summer of 1915 H. L. Alling was able to demonstrate the double character of the northeast fault below the Lower Ausable lake. Study of the map will show two valleys, separated by a narrow ridge and each occupied by a brook. Two parallel faults are responsible for the depressions and one has produced a "rotten stone quarry" for macadam at the foot of the lake. At another point much secondary calcite has developed in the sheared and brecciated rock.

The crushing of the country rock along the faults and the subsequent staining of the feldspars red or reddish brown by infiltrated iron salts, sometimes give the strongest impression to the observer that a red granite intrusive mass is before him, and one that is different from the wall-rocks. In a number of instances the writer has been puzzled by these appearances but has in the end concluded that they were secondary.

In smaller but still impressive gulches minor fractures are also brought out. One which is a favorite and easily accessible by walking from the Keene valley, is found in the northeast prolongation of the depression between Roosters Comb and Snow mountain. The gulch is so small as not to be shown on the map. It is known as Washburn flume, and is a narrow, precipitously walled trench, with sides as true as masonry and 1½ miles long.

On the road which runs southeast from the Keene valley along the course of Beede brook to Chapel pond (Chapel pond road), and at the first strong rise above the valley, there is a rock cutting in greatly decomposed anorthosite, which happens at this locality to

Plate 22



Photograph of a relief map of portions of the Mount Marcy and adjacent quadrangles. The rectilinear character of the topography is well brought out.

include a huge slab of Grenville gneiss. Two strongly marked faults are exposed with crushed and decomposed rock between well-defined walls. The master-fault strikes N. 67° W. and has a dip varying from vertical to 55° south. A smaller fault strikes N. 57° W. and is nearly vertical. A minor sheeting is also developed in a northeast direction. The first-named fault runs very true with the general course of the valley and pass containing Chapel pond. Although now at one side of the stream it was probably influential in directing the original trend of the valley. The very marked northwest and southeast courses of the minor brooks give good ground for inferring many other lines of crushing and weakness in this direction, and the pinched and sheeted rock exposed in numerous cascades corroborates their existence; but the great structural breaks are northeast and southwest.

The very peculiar and right-angled relations of the drainage lines led Prof. A. P. Brigham, from a study of the maps of the Mount Marcy quadrangle and its neighboring ones to the east, southeast and south, to describe them and give the name "trellised drainage" to them.[1] The name is appropriate and descriptive. This particular area furnishes its best illustration. The bedrock projects so generally in the higher mountains that the mantle of glacial drift has not sufficed to divert the drainage from the lines of structural weakness and superimpose a new system, not dependent upon them.

While the writer is convinced that these peculiarities of the drainage are primarily due to fault-lines, and that a great number of other faults exist, than those plotted on the map; yet only those have been indicated by a special symbol which seemed so well demonstrated by crushed zones and by pronounced escarpments as to leave little room for doubt in the mind of an observer. The northeasterly lines have been so often occupied by the basaltic dikes, which are regarded as Precambrian, that the faults themselves, if this assumption of the age of the dikes is true, must be still older than the dikes.

Areal distribution of the several formations. The Grenville is chiefly in the northeastern border of the quadrangle. It is best developed on both sides of the East branch, but is greatly cut up by the intrusives. Some prospecting pits have disclosed the limestones west of Owl's Head peak. There is also the included limestone southeast of the Cascade lakes. If the interpretation of the

[1] Brigham, A. P., "Note on Trellised Drainage in the Adirondacks," Amer. Geol., 21:219, 1898.

dark rocks in the valley of Johns brook, and in the bed of Roaring brook near the trail to the summit of Giant and at many other cited places, as included, and impregnated Grenville gneiss, is correct, we have these various outlying fragments. Other cases are known on Baxter, Gothics, Rooster Comb and other peaks, while probably many additional instances of the same exist and may from time to time be observed as fires or floods expose ledges not visible in former years or in localities unobserved as yet. The exposures are of limited extent and may be missed in the wooded areas.

An exposure of the Grenville of a very characteristic sort, constitutes the extreme northwestern hill of the quadrangle and extends into the Santanoni sheet to the west. Limestones, quartz-diopside schist, rusty gneisses and even quartzite, if we cross the border a short distance, are all present.

The anorthosites cover almost all the quadrangle. They are the predominating rock of this core-area of the mountains. They are less in relative amount in the surrounding quadrangles. In the Lake Placid and Ausable areas in the north and northeast, the geology is more complex.

The syenites are developed along the extreme northern border and project southward into the valley of the East branch for about 2 miles. They are strongly gneissoid and to what extent Grenville gneisses of similar mineralogy may be mapped in with them, it is impossible to say. The mineral compositions of these two approach each other so closely that despite microscopic work the writer has often been puzzled. Dark green rocks, consisting of microperthite, augite, hornblende and sometimes hypersthene have been mapped as of the syenite series, even though having varying amounts of quartz and showing gneissoid foliation. Differences of opinion might easily arise regarding them; the more naturally because the syenitic rocks favor the limited area containing the Grenville limestones.

Of the undoubted basic gabbro series, we have discovered only the two exposures of gabbro-syenite; the great dike at Avalanche lake, and the one to the northwest of it at the entrance to Indian pass in the edge of the quadrangle. In both cases the exposures are dikes.

The basaltic dikes are widely distributed. The following tabulation will best describe them. The table brings out the fact that all but the two camptonite dikes in the Ausable river, follow the northeast fault-lines. The two camptonites run east and west or nearly so. The thickest dike is 9 feet. Where marked by an asterisk, they have been microscopically determined.

LOCATION	BEARING	THICKNESS	VARIETY
Pass northwest Pitchoff mt	N. 58° E. 60° E.	2 ft	Diabase
Opposite Cascade Lake Hotel	Northwest	6 ft. and small branches	Diabase*
East branch Ausable river. Northern edge of quadrangle	N. 75° W. 90°	5 to 6 ft	Camptonite*
	E. and W. 90°	5 ft	Camptonite*
Brook bed west of Weston mine; 2 dikes	N. 55° E. 90°	3 ft.; 9 ft	Diabase
Southeast side of Baxter mt	N. 45° E. 90°	1 ft	Diabase
High Falls, on trail to Indian pass	N. 60° E. 90°	3 in	Diabase
North slope of MacIntyre mt. half mile below summit	N. 70° E	1 ft. 6 in	Diabase
West side Table Top mt. Marcy trail	N. 45° E. 90°	2 ft	Diabase
Johns brook below Ore Bed brook; 3 dikes	N. 27° E.; N. 67° E.; N. 62° E	1 to 3 ft	Camptonite*
Northwest slope Wolf Jaws above Johns brook; 3 dikes	N. 45° to 60° E	1 to 4 ft. 6 in	Diabase
East side Rooster Comb mt	N. 45° E	Uncertain	Diabase
Flowed lands	N. 65° E. 90°	1 to 2 ft	Diabase
Indian Face	N. 34° E	7 in	Diabase
East branch, 2 miles southwest Ausable Club	N. 34° E	2 to 3 ft	Diabase*
Noonmark trail; 2 dikes	N. 65° E. 90°	1 ft. 3 in	Diabase*
	N. 65° E. 90°	6 ft	Diabase*

Undoubtedly there are more dikes in the quadrangle, some of which may be noted by other observers from time to time. Of those recorded, all are in the northern two-thirds of the area.

6

ECONOMIC GEOLOGY; MINERALOGY

Economic geology. With the passing away of the old-time forges, the small mining industry ceased as well. The only iron mines of importance were the Weston mines, which have been described in detail on pages 22–27. They are unique in Adirondack geology in supplying ore from deposits in limestone walls, and are believed to be due to contact metamorphism. In the syenitic gneisses in the slopes between Owl's Head peak and Keene Center, but just beyond the edge of the Mount Marcy sheet, an opening was made years ago on a narrow body of lean ore, locally known as Rogers ore bed. Much hornblende was associated. The exposure seemed to be a basic streak in the syenitic gneiss.

Magnetite is known in Cascade mountain near the included and metamorphosed limestone described on pages 17–20. Only a small amount was ever blasted from the steep precipitous front.

The name Ore Bed brook for the tributary of Johns brook would suggest an ore-body, and of its existence stray statements have been heard; but personal search according to directions failed to locate the prospect. One would anticipate titaniferous ore from the local geology.

The writer's assistant, Charles H. Fulton, noted a narrow lenticular streak of supposed ore about 400 feet below the summit of Mount McComb, where it had been exposed by a great landslide. A thin section of it revealed about four-fifths hypersthene and one-fifth magnetite, presumably titaniferous, as the country rock is anorthosite.

In the improvements of the roads which have been carried out in the northern portion of the quadrangle, green syenite has been broken for macadam, in the northwest foot of Baxter mountain. On the south side of Baxter mountain about a mile east of the East branch a broad decomposed zone of faulted and crushed anorthosite has been dug for roads for many years. It is known as Beede's rotten stone quarry. Abundant rocks in the boulders and ledges are everywhere available for highway work.

In the days of the forges limestones was somewhat quarried, and one or two ledges have been opened in old times in the northeastern portion of the area. At present, however, there is no call for it.

In mineral resources the area is, so far as known, not important.

Mineralogy. *Barite.* A vein of crystalline barite has been observed by H. L. Alling crossing the portage trail midway between the two Ausable lakes. Its strike is approximately N. 30° W. and its thickness is 5 to 8 inches. It is creamy buff in color. The wall-rock is anorthosite. Under the microscope the barite shows evidence of crushing, and contains minute augites and magnetites. The specific gravity was roughly determined at 4.35. It is of interest to note that an analysis of pyroxenic anorthosite from Elizabethtown, by W. F. Hillebrand,[1] yielded BaO, 0.05 per cent.

Calcite in coarsely crystalline cleavage pieces is to be found in the ledges of Grenville limestone and especially in the dumps of the old Weston mine.

Diopside in beautiful, green, rounded crystals is disseminated in the included mass of Grenville limestone opposite the Cascade Lakes Hotel. It is described on pages 19, 20.

Garnet is abundant at the Weston mine, and in the contact zones. In the latter it is a salmon pink color, when observed in thin section. It has not been observed in well defined crystals. An analysis is given on page 21.

Hedengergite, the iron-bearing pyroxene, was determined by Max Roesler in connection with the garnet reaction rims.

Hypersthene is occasionally met with in fairly coarse masses in the anorthosite. An analysis is given on page 31.

[1] N. Y. State Mus. Bul. 138, p. 36.

Labradorite is universal in the anorthosite. When crushing and granulation have not destroyed the larger crystals, beautifully striated cleavage fragments may be obtained. Occasionally the characteristic play of colors may be seen.

Magnetite in massive form may be found in the dumps of the old Weston mine, and at the other small openings. No well-defined crystals have been met.

Orthoclase, besides being a constituent of the syenites, appears in an occasional pegmatite vein. One such vein was observed by C. H. Fulton on the summit of Mount Porter.

Wollastonite of pearly, fibrous character was opened by blasting a ledge in 1909 in road improvements on the east side of the East branch about one-fourth of a mile south of the edge of the sheet. It was a component of a small contact zone apparently produced by syenite on Grenville limestone. The amount was not large.

GLACIAL GEOLOGY

BY HAROLD L. ALLING

Introduction

The crystalline rocks of the Adirondack quadrangles have usually received more attention than the Pleistocene geology, yet glacial phenomena of the Mount Marcy quadrangle are so striking that they can not fail to impress the summer visitor or resident. When the terraces and beaches of former but now extinct lakes are traced and their various outlet channels are located and correlated, it is possible to decipher a history of glacial times that is full of interest. The responsibility for the presence of several groups of glacial lakes must be ascribed to the damming of valleys by the ice sheet. In the two parallel valleys, the Keene valley, with which we have much to do, and the Elizabethtown-Pleasant valley to the east, the drainage was northward, but the ice body, preventing the normal escape to the sea, flooded these depressions with standing waters. Each definite pause assumed by each level was controlled by lateral outlet channels. As the ice retreated northward, lower and lower spillways were opened, with a consequent lowering of the waters, initiating lakes of lower altitudes.

In order to follow the succession of the glacial waters in the Mount Marcy sheet with any satisfaction it is necessary to describe briefly some of the glacial phenomena of adjacent quadrangles, but such excursions will be limited to features of the lakes that in whole or in part once covered portions of the quadrangle.

Although positive evidences of multiple glaciation in the Adirondacks are not forthcoming, pre-Wisconsin glaciation in Pennsylvania, New Jersey and New England has been established so as to lead us to conclude that this area has been subjected to continental ice bodies more than once. In some of the brook valleys the depth of the drift is enormous and often a difference in the degree of weathering of different levels can be detected. In the valley which extends from the slopes of the Cascade-Porter mass northeastwardly to the East branch of the Ausable, the thickness of morainal material is certainly not less than 200 feet and is one of the most promising deposits harboring evidence of pre-Wisconsin ice action within the quadrangle.

All evidence points to the conclusion that at the maximum extent the Adirondacks were completely buried by the ice, which spread

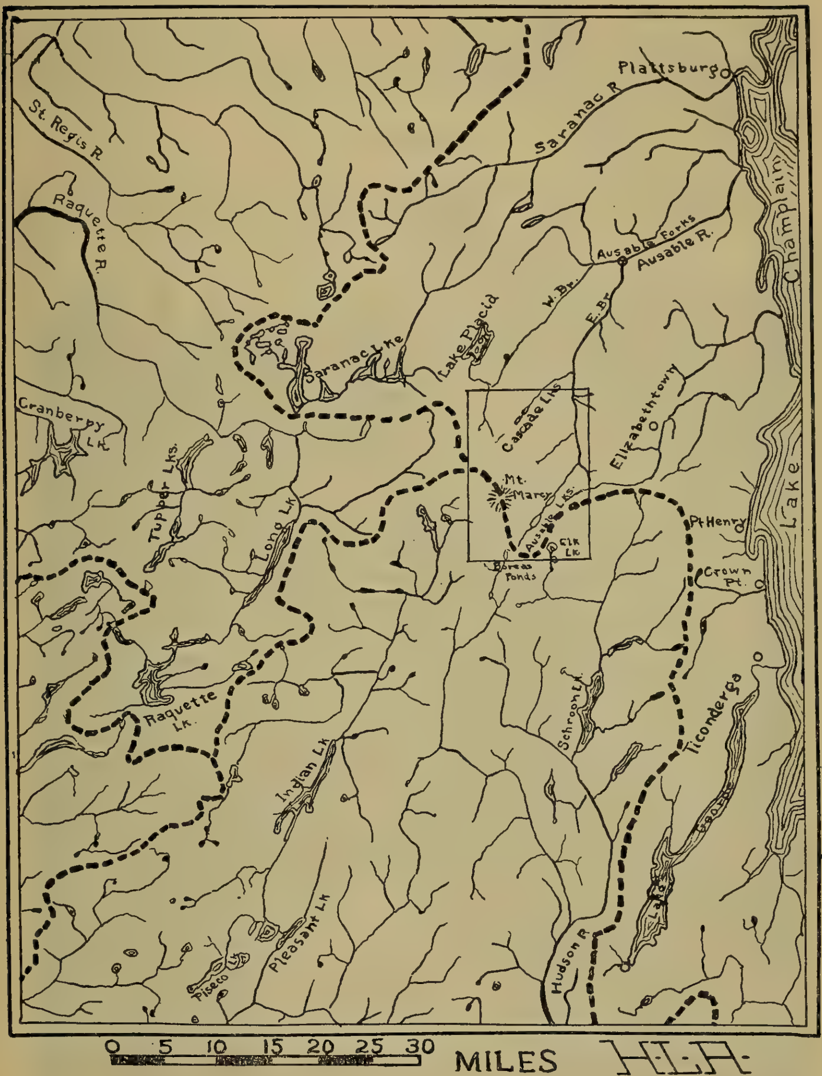


Fig. 7 Sketch map showing location of the Mount Marcy quadrangle and the three drainage basins; the St Lawrence, Champlain, and Hudson rivers

over the major part of the State, reaching as far south as New York City. In order to provide a sufficient gradient for such an expanse of ice the surface of the ice that moved over the quadrangle has been estimated to have been from 8500 to 12,000 feet above sea level.[1] To this enormous load upon the land surface is attributed the well observed phenomenon of deformation, to which we shall return later.

Movement

Two occurrences of glacial striae have been noted in the quadrangle; they are situated beside the highways in the valley of the East branch of the Ausable river. The direction of both of these striae is due south, indicating that the topography was the controlling influence affecting the course taken by the waning ice lobes lying in the valleys. The more general direction of the ice flow would be shown by striae on the mountain summits, but their records have been destroyed by weathering. It is believed, however, that the ice that covered the quadrangle flowed southward with a slight deviation to the west.

Erosional Work

The residual soil resulting from weathering during interglacial periods was completely removed by the ice, the mountains smoothed and their contours subdued. This effect of ice action is recorded in the comparatively fresh condition of the rocks on exposed ledges, and in the dignity of the round dome of Marcy probably due to glacial erosion.

The many amphitheaters and little rocky pockets on the mountain sides are due, in all probability, to the plucking action of the ice. These cirques have been attributed to the combined work of the continental ice bodies and to local glaciers.[2] "An amphitheatre with steep walls . . . is a favorite form for the Adirondacks, being well shown on . . . the Gothics,"[3] the Cascade-Porter massif, Big Slide, Haystack and Noonmark. Occasionally small ponds are located on the southern or lee side of the mountains, apparently occupying basins plucked out by the ice. Lost pond in the southwestern corner of the Ausable sheet, the pond on Clements mountain in the quadrangle to the north, and the Giant Washbowl and Dipper are examples.

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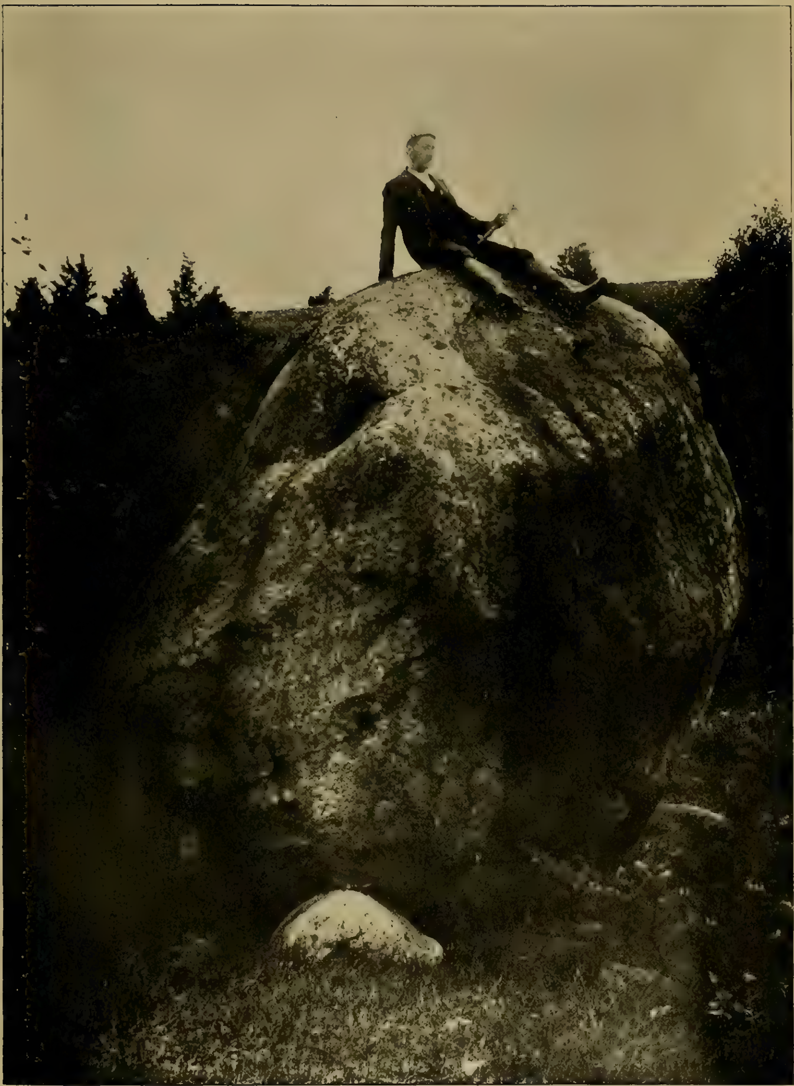
[1] Fairchild, H. L. Bul. Geol. Soc. Am., 24:136. 1913. After Shackleton.

[2] Ogilvie, I. H., "Glacial Phenomena in the Adirondacks," Jour. Geol., 10:406. 1902. Johnson, D. W., "Date of Local Glaciation in the White, Adirondack, and Catskill Mountains," Bul. Geol. Soc. Am.

[3] Kemp, J. F., N. Y. State Mus. Bul. 21, p. 63. 1898.

Plate 23



Glacial boulder, northeastern portion of the quadrangle. The rock is anorthosite, and is about 12 feet in diameter.

The major fault-line valleys furnished passes for ice tongues to push through. The slopes were smoothed and carved into U-shaped defiles. Such phenomena are observed in the Cascade fault-line valley, and the valley holding the Lower Ausable lake, which were blocked by crescent-shaped moraines deposited upon the retreat of the ice lobes.

The occurrence of glacial boulders is quite common, some of which appear to have been transported from great distances, while others can be traced to parent ledges in the neighborhood. Rounded boulders of "Potsdam" quartzite have been noted all over the quadrangle. Large irregular slabs of Potsdam sandstone and quartzite are encountered in some of the brook valleys where the drift is abnormally thick. In the brook valley where the Weston mines were located irregular nonglaciated flagstones were found in such numbers as to strongly suggest that a ledge of the Potsdam existed there before the ice invasion broke it up. Similar occurrences in the Elizabethtown [1] and Lake Placid [2] quadrangles together with outliers [3] point to the conclusion that the Adirondacks were more or less completely mantled by the Potsdam. Dr D. W. Johnson suggested to the writer that the sawtooth shape of the Niagara mountain block fault in the southeast corner of the quadrangle may have been preserved by the deposit in it of a ledge of Potsdam sandstone that was subsequently eroded and destroyed by the ice. Doctor Kemp reports that no remnant was found.

Constructional Work

There is little true morainal material,[4] for most of it has been modified by water; [5] the movement of the ice during the maximum advance having, evidently, been too vigorous for deposition and the material that was deposited as the ice retreated having been sorted by the waters of the glacial lakes.

The recessional moraines appear to be largely confined to the fault-line valleys, being formed by the ice tongues as they withdrew from the narrow defiles. At the southwestern ends, in the broad valleys, the rate of retreat was slow and moraines were formed; but

[1] Ruedemann, R., N. Y. State Mus. Bul. 138, p. 62.
[2] Alling, H. L., N. Y. State Mus. Bul. in press; Bul. Geol. Soc. Am., 27:650. 1916.
[3] Miller, W. J., N. Y. State Mus. Bul. 182, p. 44.
[4] Cushing, H. P., N. Y. State Mus. Bul. 115, p. 495.
[5] Ogilvie, I. H., Jour. Geo., 10:406.

in the narrow valleys the melting of an equal amount of ice would produce a much more rapid recession, giving but little opportunity for the deposition of material. Again at the northeastern ends of the passes the ice tongues paused long enough to deposit another series of moraines. Such recessional moraines blocking both ends of the Cascade lakes fault-line valley have resulted in the basin within which the lakes are now situated. Originally but one lake occupied the depression. A similar group of moraines act as a natural dam retaining the waters of the Lower Ausable lake. Man has come to the aid of nature and reinforced and heightened it. It is very likely that only one lake lay in the Ausable lake fault-line valley before the accumulation of the delta sands of Shanty and Haystack brooks.

Doctor Kemp has already called attention to the morainal dam confining Chapel pond. This long narrow ridge is an esker; the glacial deposit of a stream flowing beneath the ice. Another esker is excellently well displayed beside the state highway from Keene to Elizabethtown half way up " Spruce hill." It can be traced for nearly one-fourth of a mile.

The preglacial drainage has been modified by glacial material of one kind or another in several localities. An excellent example of stream diversion is south of the town of Keene on the northern boundary of the quadrangle, in the East branch of the Ausable river. In this comparatively broad valley we note an unnamed hill, around the two sides of which the two highways leading to Keene valley circle. To the west of the hill the present river rushes between steep walls of syenite complexly involved with various Grenville rocks, experiencing rapids and falls. It is clearly a postglacial channel and is one of the beauty spots in the quadrangle. On the other side of the hill the preglacial channel is plainly visible although now blocked by sands of a lateral delta. The accompanying map shows the probable course taken by the branch before the invasion of the ice.

Farther upstream a similar state of affairs is suspected, but not so easily proved. Back of the Ausable Club (Beede on the map) the present river leaves the fault-line valley, following a recently formed gorge in anorthosite. One-half of a mile to the east the topography and the sand plains seem to indicate that the preglacial channel followed a direction across the bedrock, now under the eroded surface of the terraces of the Saranac glacial waters, the probable course being indicated by the road in its circuit around the golf links.

Local Glaciation

The study of lateral moraines in the brook valleys, the poorly developed and incipient cirques on the mountain slopes and hanging tributary valleys has convinced the writer that local glaciation has occurred in the Adirondacks. In 1916 Doctor Johnson demonstrated to the satisfaction of the writer that such action took place *after* the withdrawal of the continental ice sheet.[1] In the cirque on the eastern slope of Esther mountain, a portion of the Whiteface massif, in the Lake Placid quadrangle, we found the remnant of a local moraine convex down stream. This cirque valley slopes northeast offering a favorable opportunity for the continental ice to force a tongue into it and to deposit a recessional moraine; but this would have a crest declining southwest, while that found has the opposite inclination. In the valley of Slide brook lateral moraines are situated on both sides of the stream and appear to assume similar positions and forms.

Rich [2] has shown that local glaciers existed in the Catskills which is a region less likely to support local glaciers than the Adirondacks, thus lending support to the writer's contention.

Extinct Glacial Lakes

There are extensive sandy plains within the quadrangle that undoubtedly owe their origin to the continental ice. Unless shore line features and outlet channels can be found to show that they are of lacustrine parentage they are regarded as outwash plains formed in front of the melting ice, the débris being swept into the valleys by the glacial streams. Such plains are often dimpled with ice-block kettle holes in contrast to lake flats and bottoms. The great sand plain of the South Meadows country, in the northwest corner of the quadrangle, is an excellent example of this type of glacial deposit. When first observed it was regarded as an outwash plain but remnants of concordant beaches were found on Scotts Cobble and Pitchoff mountain to question such interpretation, and thus the plain is explained as a glacial lake deposit. It is quite reasonable to believe, however, that it may have been an outwash plain modified

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[1] Johnson, D. W., "Date of Local Glaciation in the White, Adirondack and Catskill Mountains," Bul. Geol. Soc. Am. 28:543–552, 1917

[2] Rich, John L., "Notes on the Physiography and Glacial Geology of the Northern Catskill Mountains," Am. Jour. Sci., 39 lv, Feb. 1915, p. 154; "Local Glaciation in the Catskill Mountains," Jour. Geol., 14:113–21, 1906; "Local Glaciation in the Catskill Mountains," 29th Annual Meeting, Geol. Soc. Am., paper 12, Dec. 27, 1916. Abstract Bul. 28:133, 1917.

and smoothed by lake waters. The Boreas ponds — Elk lake areas in the southern portion of the sheet are similar.

Conditions Favorable for Glacial Lakes in the Region

A number of important factors favored the formation of several series of local glacial lakes in the east-central Adirondacks which formerly existed in the area covered by this bulletin. Among the conditions we note: (1) northward draining valleys, sloping toward and blocked by the ice lobes; (2) the complete isolation of such valleys by mountain ranges; and (3) the presence of a huge ice ring that completely surrounded the Adirondack highlands impounding vast quantities of water. The Mount Marcy quadrangle was situated close to the northeast rim of this ice ring. The large amount of sand and gravel for the formation of deltas, terraces and beaches, makes possible the recognition of the different lake levels in the valleys. The cause of the great quantities of sand is discussed later on.

As noted above, Taylor [1] was one of the first to describe a number of glacial lakes in the east-central Adirondacks, although he did not attempt to separate and correlate the different levels with any great care. A year later Kemp [2] noted two or three sets of deltas in the Keene valley.

In dealing with the glacial lakes the writer has for convenience classified them in three sections: (1) the western section, which included the area around Lake Placid, west of the Wilmington notch; (2) the eastern section, or the Keene valley division in the valley of the East branch of the Ausable; and (3) the Elizabethtown-Pleasant valley group. The last section does not come under discussion here.

Upper Series

Western Section

As the ice sheet began to wane, the highest peaks of the Adirondacks were the first to be uncovered, playing the rôle of islands in a sea of ice[3] (see figure 8). Slowly these islands became larger, surrounded by a growing accumulation of water impounded by the ice. These waters found escape over the ice to the south and eventually passed to Susquehanna drainage. This progress of melting was continued until entire mountain ranges were exposed.

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[1] Taylor, F. B., "Lake Adirondack," Am. Geol., 19:392–96. 1897.
[2] Kemp, J. F., N. Y. Mus. Bul. 21, p. 60. 1898.
[3] Fairchild, H. L., N. Y. State Mus. Bul. 160, pl. 11.

The South Meadows lake. The highest definite level recognized by the writer in the Mount Marcy quadrangle is the South Meadows lake, so named from the remnants in the South Meadows country. About one-fourth of the area covered by the lake is situated in the Mount Marcy sheet; the Lake Placid, the Saranac and Santanoni quadrangles coming in for equal shares of the rest. It is believed that the ice consisted of three lobes; one covered the greater portion of the Saranac quadrangle, the second lobe was fed through the

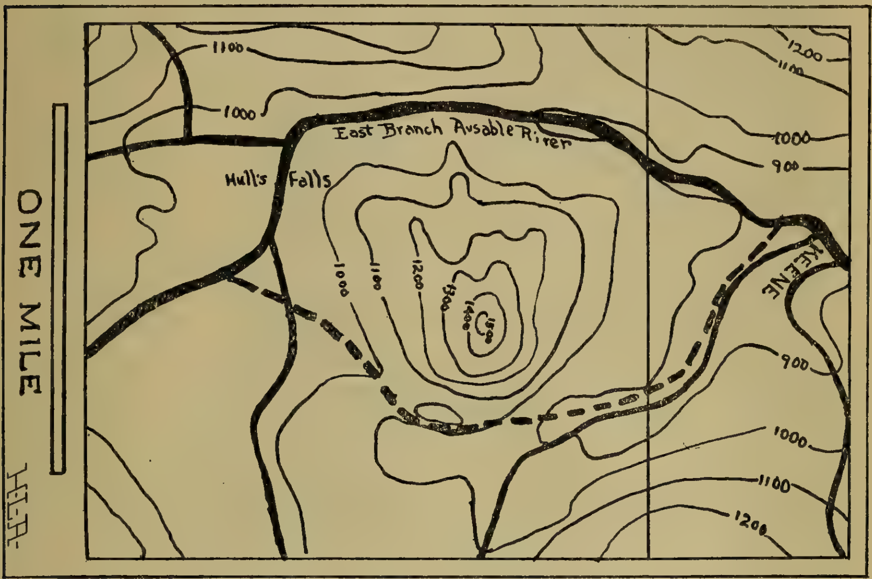

Fig. 8. Map showing the preglacial channel of the East branch of the Ausable river south of Keene. Light lines, contours, 100 foot interval; heavy continuous lines, streams; heavy broken lines, preglacial channel; straight line near top, boundary between Mount Marcy and Lake Placid quadrangles. North is at the right hand side of figure.

narrow depressions to the east and west of the Whiteface-Esther-Wilmington massif and covered the territory where Lake Placid now lies; the third and most eastern lobe, here considered, completely filled the valley of the East branch of the Ausable river, including the Keene valley.

The South Meadows lake was of irregular shape, some 10 miles long and wide, containing a number of islands, among which Mount Jo and Seymour mountain can be mentioned. Its outlet has not, as yet, been definitely established, but a very probable one is offered as follows: It begins at the swamp just south of Alford mountain in the Santanoni quadrangle on the Essex-Franklin county boundary line (altitude 2105.5 feet, 2020 on the map), it passes westward through the narrow pass (altitude 1980 feet) directly south of Van Dorrien mountain to Blueberry pond. Continuing westward into the Long Lake quadrangle, on the boundary between the two maps, it turns to the southwest and passes three-fourths of a mile south of Palmer brook. When within a mile of the Racquette

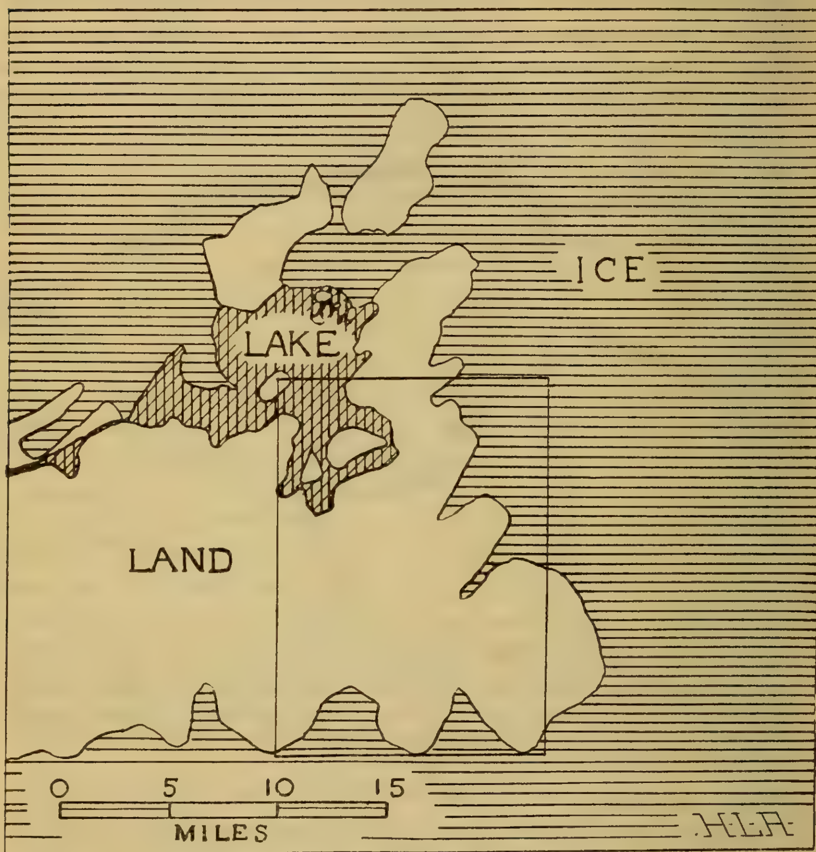

Fig. 9 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 1. The South Meadows lake, altitude 2210 to 1960 feet.

river the course turns directly south over Brueyer pond. This river course is a mere suggestion, as actual field work has not been undertaken in the rugged and inaccessible Santanoni quadrangle. Probably the waters flowing in this channel did not form a single river but consisted of a chain of lakes and ponds.

A number of unmistakable beaches exist on the shoulders of the

Plate 24

Beach of glacial lake South Meadows, altitude 2172 feet, on the southern shoulder of Sentinel range, Mount Marcy quadrange.
H. L. Alling, 1916 photo.

Sentinel range and on Scotts Cobble, on the northern edge of the Mount Marcy sheet. One series ranges from 2123 to 2172 feet in altitude.[1] These figures, in all probability, represent the water levels during the early stages of the lake. Sand plains with altitudes close to 1960 indicate that the lake level was undergoing constant lowering. It is suggested, as a reasonable explanation of this lowering, that as the small ice lobe 3 miles east of the highest peak of Ampersand mountain retreated, it allowed escape through the channel of the East branch of Cold brook and then south to the Van Dorrien pass which held the waters to 1980 feet.

The fault-line valley containing the Cascade lakes was probably blocked by a glacial lobe and morainal material which prevented escape to the east; the drainage of the South Meadows being to the west as suggested above.

Western portion of Upper Lake Newman. With the gradual retreat of the ice and its constant shifting position, new and lower outlets were uncovered. Succeeding the South Meadows lake the western portion of Upper Lake Newman[2] was ushered in. As the remnants of terraces and sand plains of this level are rather indefinite in character and the range of the elevations of the surfaces is considerable (1800 to 1895 feet), the writer is not unmindful that stream-filling forming an outwash plain from the glacier may be a logical explanation, yet in view of the fact that the sand plains are found over a considerable area confined within these limits, they are regarded as representing a series of lake bottoms formed by a lake (or series of lakes) whose level was experiencing periodic lowering due to the downcutting of the controlling spillways. These spillways may have been over the ice itself or a series of outlets controlled by ledges of rock. Unfortunately, however, the outlets of the lake are not positively known but in all probability the drainage was to the west, similar to that of the South Meadows lake.

This lake probably covered more territory than its predecessor but not so much of the Mount Marcy sheet, being largely situated in the Lake Placid and Saranac quadrangles. The portion of the lake situated within the Marcy map assumed a four finger-shaped body of water. Ice lobes lay to the east of the Wilmington notch in the valley of the East branch of the Ausable preventing any connection between the eastern and western portions of the area.

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[1] Determined by a surveying aneroid barometer, corrected for temperature of the air and checked against a barograph, hence as accurate as this method permits.

[2] Alling, H. L., N. Y. Mus. Bul. 207–208. 1919.

The best preserved terraces of the Upper Lake Newman were found in the neighborhood of John Brown's grave just over the northwest edge of the sheet, along the West branch of the Ausable. The name of the lake is derived from the town of Newman, the terminus of the Delaware and Hudson Railroad, where well-preserved levels occur.

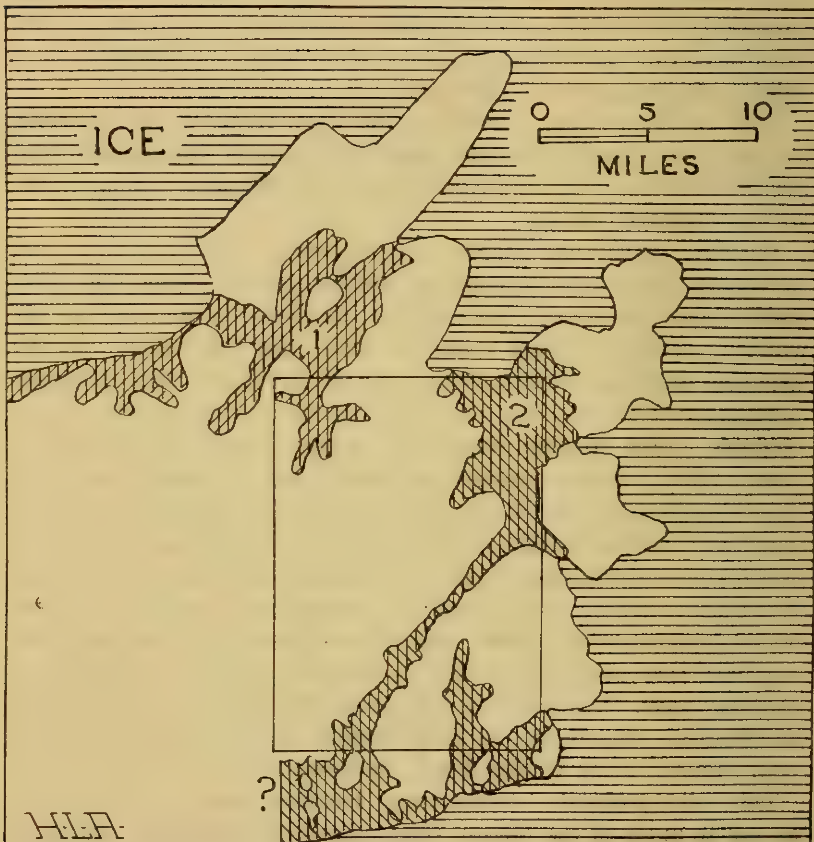

Fig. 10 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 2. (1) Upper Lake Newman, altitude, 1895 to 1800 feet. (2) The Keene lake, altitude, 2023 to 2000 feet.

The main ice dam that retained the lake was situated for a time near the southern edge of what is now Lake Placid. In the vicinity of John Brown's grave, beaches show a complete separation of Upper Newman from the succeeding lake, Lower Newman; the upper series ranging from 1800 to 1820 (one well-marked level at 1806.5 feet) while the lower group vary from 1740 to 1780 feet.

Eastern Section

The Keene lake. During most of the life of the western portion of Upper Lake Newman, the ice lobe in the valley of the East branch of the Ausable was retreating northward and allowed a growing body of water to accumulate in the Keene valley. This body of water, named the Keene lake, left terraces high up on the valley walls, especially in the brook valleys where the present streams have bisected them. The sands on the East hill, near Hurricane Lodge, at 2000 feet altitude, were probably deposited at this time. The lake filled Keene valley and thus was located mainly within the confines of the Mount Marcy sheet.

The outlet is at present believed to have been south through the double fault-line valley in which the Ausable lakes are now located into standing waters in the northern half of the Schroon Lake sheet. The two passes to the east, the Spruce Hill pass, and the Chapel Pond pass, although much lower than the surface of the water, were apparently effectively blocked by lateral ice lobes forced into them from the east, being tongues of the ice body occupying the Elizabethtown-Pleasant valley, thus making escape to the east impossible. Studies of these two passes lead to the above conclusion.

The eastern end of the Wilmington notch was uncovered by the retreat of the ice that dammed the Keene valley, furnishing a connection with the western portion of the area, permitting the waters in the valley of the East branch to fall to the level of Upper Lake Newman.

During the life of the Keene lake the area south of the Upper Ausable lake was flooded; an ice dam lay in an east and west line across the upper portion of the Schroon Lake quadrangle.[1] As this ice wall melted the waters south of the divide were separated from the Keene lake so that the Boreas-Elk-Clear pond section became a distinct glacial lake, which in turn may have been subdivided into the Boreas lake and glacial Elk lake, while the drainage of the remaining Keene lake flowed into the Boreas lake through the pass east of Moose mountain, until extinguished by the formation of Upper Lake Newman.

Upper Lake Newman. The life of the eastern portion of Upper Lake Newman was probably relatively short compared with that of the western area, for the terraces are very indefinite and the separation of the benches into an upper and a lower series does not exist, or at least can not be demonstrated. Thus soon after the establish-

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[1] Fairchild, H. L., N. Y. State Mus. Bul. 160, pl. 12.

ment of Upper Lake Newman in the Keene valley, which was confluent with the western portion situated in the South Meadows country, and in the Lake Placid and Saranac quadrangles, the outlet was changed, and perhaps rapidly deepened by the additional volumes of water from the eastern section, so that the waters fell to the level of Lower Lake Newman.

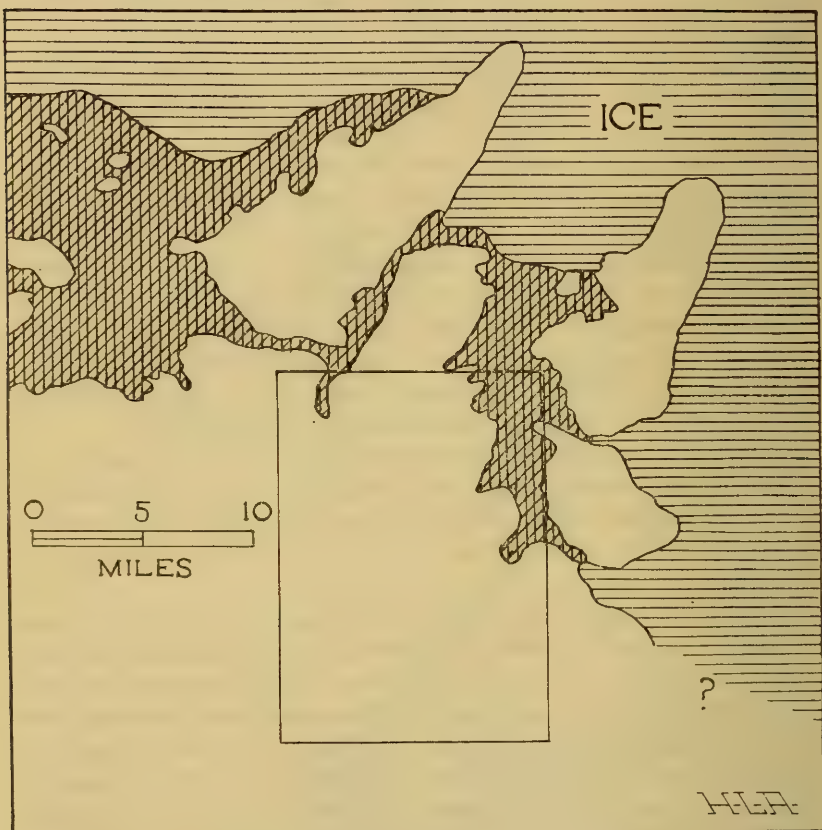

Fig. 11 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 3. Lower lake Newman, altitude, 1740 to 1780 feet.

Eastern and Western Sections

Lower Lake Newman. This lake was of still greater extent than any of the above-described bodies of water. Its northern, and especially its northwestern, extent and boundaries are still to be studied and determined. Our present knowledge, however, would lead us to conclude that the valleys occupied by the West and East branches of the Ausable river were flooded, the connecting link between the two being the Wilmington notch. This is inferred by the fact that deltas and terraces at similar heights were found to the east and west of the notch. How else could the waters of the two areas have been confluent? These waters thus flooded the Keene valley, the South Meadows country, the area occupied by Lake Placid today and the greater part of the Saranac quadrangle. Terraces are located on East hill and the hill traversed by the Keene-Cascade Lakes road.

The outlet of Lower Lake Newman is not definitely known but according to the present data it seems likely that it was to the west. It is possible, though regarded as very unlikely, that the Chapel Pond pass became an outlet at the close of this period, changing the drainage to the east.

The South Meadows, and the two Newman Lakes, probably had outlets to the west; the Keene lake drained south; but the succeeding lake (or group of lakes) had drainage to the east.

Saranac glacial waters. The series of sand plains, terraces etc. that come under this head were recognized by H. P. Cushing [1] in the Saranac region, in what is generally known as the lake belt. These levels have such a wide range of altitude, 1540 to 1660 feet, that they must have been produced by a series of glacial lakes, or have been deposited by aggrading streams which no longer exist, or by a combination of both. Doctor Cushing is of the opinion that: "these sands were probably deposited as deltas in a large irregular, shallow lake formed back of the ice tongue which occupied the 'lake belt' during its slow retreat north, the material being furnished by the subglacial and englacial streams flowing into the lake at the ice margin." [2]

As nearly two-thirds of the Saranac sheet exhibits terraces and sand plains of the higher levels, it is not inappropriate that the term Saranac glacial waters should be applied to them.

The area covered by the Saranac glacial waters varied so much during its existence that it is difficult to give the precise limits within which it lay. During the early stages it was chiefly located in the Saranac quadrangle, while during its closing episodes the Lake Placid sheet came in for its share, the southern ends of the lake levels extending into the Mount Marcy area.

The general character of the terraces is that of gentle sloping plains on the mountainsides without any prominent shore line feat-

[1] Cushing, H. P., "Recent Geological Work in Franklin and St Lawrence Counties," N. Y. State Mus. Ann. Rep't, 1900, p. 29.

[2] Op. cit.

ures, except in a few localities in the Lake Placid sheet. The indefinite nature of nearly all the sand plains strongly suggested the work of aggrading glacial streams, but with the discovery of a series of remarkable glacial outlet channels in the center of the Ausable quadrangle whose spillways correlated with almost mathematical

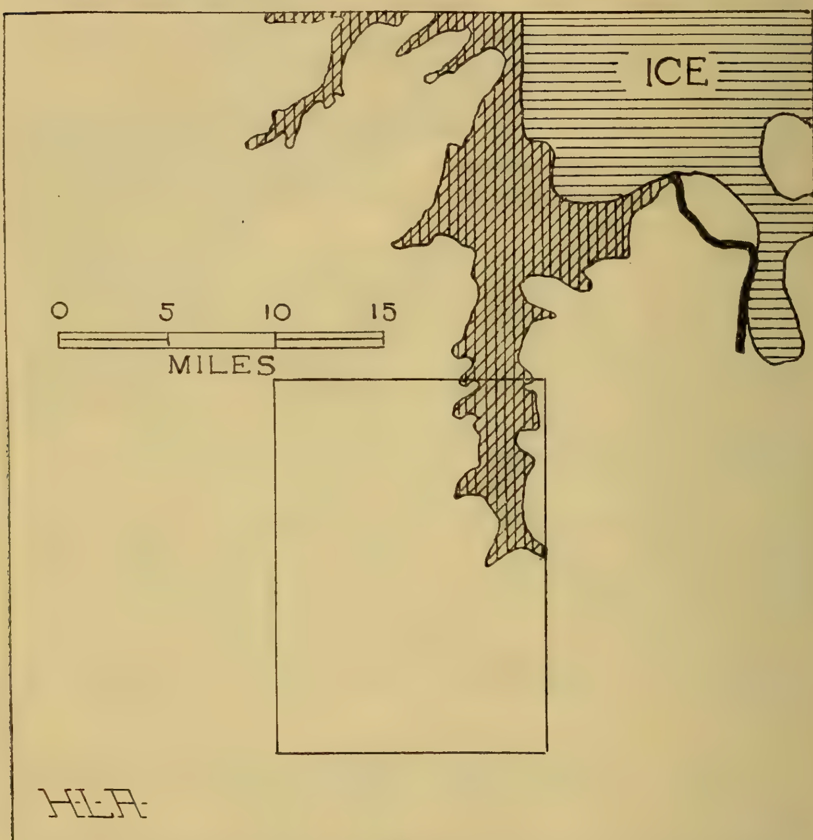

Fig. 12 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 4. Lower stages of the Saranac glacial waters, altitude of particular phase here represented, 1500 feet. Total range of Saranac glacial waters, 1450 to 1660 feet.

exactness with the beaches above mentioned the glacial lake origin of the Saranac glacial waters became clear.

Here we must depart from the confines of the Mount Marcy sheet to understand the history of these conspicuous levels.[1]

[1] Alling, H. L., " The Glacial Lakes and Other Glacial Features of Central Adirondacks," Bul. Geol. Soc. Am., 27:658, and fig. 1. 1916.

Beginning on the southern slopes of Ellis mountain, in the township of Jay, a long glacial channel extends south for a distance of some 10 miles with a dozen side outlets to the east. The lake entrance to this channel was south of Ellis mountain at the northern end of the South gulf as this north and south fault-line valley is locally called. The controlling spillways were regulated by the ice lobe that lay to the east. Thus as the ice retreated it permitted escape first by the most southern side-outlets which represent the outlets of the early stages of the Saranac glacial waters; while later lower spillways were opened farther north with a consequent lowering of the waters.

In several of these channels abandoned falls and cataracts were found, which, together with correlation of the elevations of the outlets and minor breaks in the sand plains, furnish positive evidence of the origin of these levels.

The chief cause for the indefiniteness of the levels and the lack of shore line features is attributed to the fact that the ice was the barrier controlling the spillways in many cases. Many one-bank channels exist showing unmistakable evidence of the rapid lowering of the waters.

Eastern Section

St. Huberts lake. At a lower altitude than the Saranac water levels there are scattered terraces of indefinite and sloping character situated at 1300–1340 feet elevation. They are subordinate in interest to the preceding levels as well as to those described below. There is a small but finely developed terrace at the head of Keene valley at 1300 feet. The level surface is now used as a baseball diamond. Taking this as a starting point the other terraces fit into the general scheme and thus there is the possibility of a lake level at this altitude in the series that once flooded portions of the Mount Marcy quadrangle. The most prominent remnant left of the St Huberts lake is on the northeast slopes of Owls Head now traversed by the Keene-Cascade highway, just off the northern edge of the map. Its outlet was without much doubt to the east through the gulf, south of Ellis and Bald mountains in the Ausable quadrangle, the spillways being controlled by one-bank channels which are beautifully shown in the woods on the southeast slopes of Black mountain.

The Lower Series

Confined Entirely to the Eastern Section

In descending from the higher lake levels to the lower ones, the character of the terraces changes from indefinite levels of considerable range to neat, clear-cut deltas, wave-cut cliffs and beaches confined within concise limits. No question can be raised as to the origin of many of them. They represent remains of true glacial lakes.

Wilmington lake. The history of the Wilmington lake is, perhaps, the best understood of all the local glacial lakes in the east-central Adirondacks. It is chiefly confined to the Lake Placid quad-

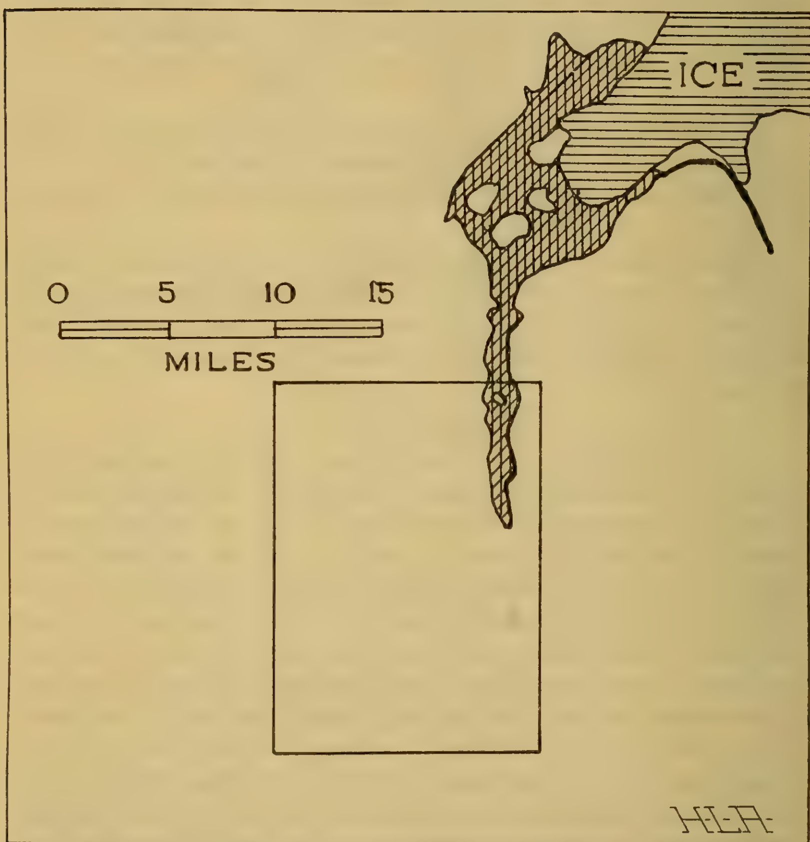

Fig. 13 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 5. The Wilmington lake, altitude 1100 to 1157 feet.

rangle, to the East branch of the Ausable river, and to the territory around the town of Wilmington but sent a southern prong into the Keene valley to the base of the Ausable Club hill.

At the foot of Johns brook, especially on the western side of the valley, there is an extensive delta with an elevation of 1100 feet.

Plate 25

Dissected remnant of delta of Lake Wilmington. At the foot of Johns brook, half a mile south of the village of Keene Valley. Present altitude, slightly less than 1100 feet. Photograph by J. F. Kemp, 1915.

Remnants are situated on the east side of the valley composed of very fine sand while the western exposures are made up of coarser materials. At the valley wall distributary channels are well shown; pebbles and boulders as large as one's fist or larger are common. It is evident that the delta materials came from the Johns Brook valley and were deposited in standing waters by the ice-fed Johns "river."

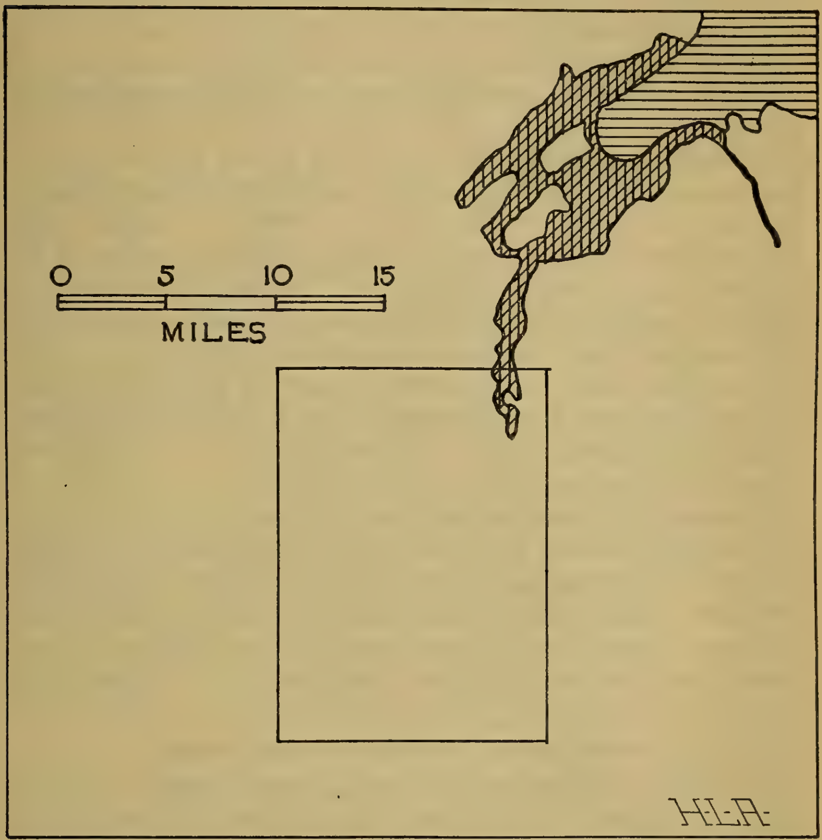

Fig. 14 The glacial lake succession in the Mount Marcy and adjacent quadrangles. Stage 6. The Upper Jay lake (upper phase), altitude, 1017 to 1046 feet.

A number of beaches of the lake are beautifully shown on a hill a mile north of Keene, in the Lake Placid sheet. The altitude of the best developed one is 1113 feet. Farther to the northeast we find the spillway at the entrance of the gulf in the Ausable sheet at 1157 feet. The cause of these apparently nonconcordant figures is due to postlacustrine deformation and tilting; a subject treated more in detail on a later page.

The outlet of the Wilmington lake was through the gulf and hence southeast to cross and then south to near Elizabethtown. The escaping waters were forced to take such a course because of the ice lying in the valley of the East branch of the Ausable with its southern wall at Lower Jay. Another body of ice blocked the narrow valley now occupied by Trout pond.

The gulf channel contains a number of Pleistocene cataracts of which the remarkably beautiful Copperas pond is the most striking example.

Upper phase of Upper Jay lake. The Upper Jay lake, like its predecessor, the Wilmington lake, has left terraces and beaches that are very definite in character. One beach on the hill a mile north of Keene is 1017.7 feet in altitude while still another in the Ausable sheet is 1045 feet above tide. The controlling spillway is situated 1½ miles north of Bald mountain. The part of the lake that existed in the Mount Marcy area was only 2 miles long.

Lower phase of the Upper Jay lake. A lower phase of the Upper Jay lake is indicated by beaches and terraces in the Lake Placid sheet at 994 feet, and was almost entirely confined to the Lake Placid and Ausable quadrangles.

The lakes that succeeded the Upper Jay lakes do not concern us as they did not occupy any portion of the Mount Marcy quadrangle. Yet for an understanding of the postlacustrine deformation the well-established levels are here listed, with their altitudes: Haselton lake, 967 feet; Lower Jay lake, 930 feet; Otis lake, 903 feet; Rocky Branch lake, 860 feet; "Clifford" lake, 835 feet; "Marine level," 646 feet.

Postlacustrine Deformation and Tilting[1]

It has been pointed out that at the maximum extent of the continental ice sheet the load upon the land surface must have been tremendous and must have subjected the land to great compressional stress, which caused it to be depressed below its former level. Since the ice was thicker in the north than in the south the amount of deformation was greater in the northern part of the State.

With the removal of the load by the melting of the ice the land has "sprung" back, thus elevating the surface and tilting the shore

[1] This subject of deformation has not yet been fully considered by structural geologists in the light of isostasy.

line features of the glacial lakes. It has been shown by Fairchild in a number of papers[1] that the character of the postlacustrine uplift was a lifting in the form of a warped plane with the amount of warping greater to the north. The lines of equal uplift since the time of the marine level incline in this portion of the State west-northwest to east-southeast (20 degrees from the latitude parallels). The zero isobase passes far south of New York City. The 600 foot isobase touches the northeast corner of the quadrangle, while the 553 foot isobase enters the sheet in the southeast corner. These figures give the total uplift for the region since the marine waters occupied the Hudson-Champlain embayment. The figure for the amount of tilting for this marine plane in this region is 2.71 feet a mile taken along a north and south line, or 2.83 feet perpendicular to the isobase.

Although Fairchild's papers form a very valuable contribution to this subject, there exists some uncertainty as to the character of the uplift. (1) Was the upward movement gradual and uniform or (2) was it in the nature of a wave or a series of sudden uplifts? The writer believes that the problem will be clarified by the measurement of beaches, deltas etc. situated at higher levels than the marine plain to supplement those mapped at the lower altitudes. The shore phenomena of the lakes above described afford an opportunity to determine the amount of tilt of the land surface, for they furnish a series of datum planes higher than those in the Champlain valley, which was occupied by the ice during the entire period that these lakes existed. Fairchild believes that his figures give the *total* uplift since glacial times. The writer feels, however, that this conclusion is based upon the state of affairs that prevailed *during* and *after* the marine stage and overlooks the shore phenomena of higher lake levels. Although accurate measurement of the amount of tilt of the lake levels of the Mount Marcy and adjacent sheets is exceedingly difficult, for the chances of error are great, the table given below would indicate that the uplift was taking place *while* the ice was melting from the area.

[1] Fairchild, H. L., "Pleistocene Uplift of New York and Adjacent Territory," Bul. Geol. Soc. Am. 27:235–62; "Post-Glacial Marine Waters in Vermont," Rep't of Vt. State Geol. for 1915–16.

Deformation table

LAKE	ALTITUDE (a) Southern station	ALTITUDE (b) Northern station	DISTANCE MILES	TILT, FEET A MILE
1 South Meadows	2105.5	2123.0	6.5	3.7–
2 Upper Newman	1806.5	1823.5	6.0	3.52
3 Keene	2000.0	2023.0	8.0	3.48
4 Lower Newman	1725.7	1743.0	5.75	3.32
5 Saranac waters	1610.0	1637.5	9.12	3.2–
6 St Huberts	1300.0	1321.0	6.5	3.1–
7 Wilmington	1100.0	1157.0	16.75	2.94
8 Upper phase Upper Jay	1017.7	1046.0	10.2	2.80
9 Lower phase Upper Jay	993.9	1024.0	11.0	2.75
10 Haselton	967		....	2.71
11 Lower Jay	930		....	....
12 Otis	903		....	....
13 Rocky branch	860		....	....
14 "Clifford"	835		....	2.70
15 "Marine level"	646		....	2.71

Location Index to Deformation Table

1a Van Dorrien pass, one-half of a mile south of Van Dorrien mountain; Santanoni quadrangle.
1b Beach, shoulder of Pitchoff mountain; Mount Marcy quadrangle.
2a Beach, one-half of a mile north of John Brown's grave; Lake Placid quadrangle.
2b Terrace-bench, one-fourth of a mile north of Owen pond; Lake Placid quadrangle.
3a Terrace, foot of Lower Ausable lake; Mount Marcy quadrangle.
3b Beach, foot of Lower Cascade lake; Mount Marcy quadrangle.
4a Terrace, seven-eighths of a mile west of Owls Head; Mount Marcy quadrangle.
4b Beach, one-half of a mile north of Harrietstown; Saranac quadrangle.
5a Wave-cut cliff, 3 miles north-northeast of Keene; Lake Placid quadrangle.
5b One-bank control channel, 2 miles east-southeast of North Jay; Ausable quadrangle.
6a Baseball diamond, near Ausable Club (Beede); Mount Marcy quadrangle.
6b Terrace-beach, 1 mile west-northwest of Keene; Lake Placid quadrangle.
7a Delta, foot of Johns brook; Mount Marcy quadrangle.
7b Spillway, Gulf; Ausable quadrangle.
8a "Keene Hill," one-half of a mile north of Keene; Lake Placid quadrangle.
8b "Lower Jay Hill," 1½ miles northeast of Lower Jay; Lake Placid quadrangle.
9a One-half of a mile northwest of Keene; Lake Placid quadrangle.
9b One and three-fourths miles northeast of Lower Jay; Ausable quadrangle.

It will be noticed that the rate of tilt decreases as one passes from the South Meadows lake to the lower altitude of Lake Haselton; the tilt of the latter appears to be the same as that of the marine plain. If any confidence can be placed in the figures it would seem that the waters below and including Haselton drained directly into the marine waters. Since the process of warping and uplift were synchronous it would appear that the total amount of uplift for the Mount Marcy quadrangle since glacial times is greater than the amount, 600 feet for the northeast corner, proposed by Fairchild.

Cause of the Large Amount of Material Available for the Formation of Terraces

One of the striking features of the glacial geology of the Adirondacks is the small amount of true morainal material[1] unmodified by water[2] as contrasted with the vast quantities of sand and gravel in deltas, terraces etc., when compared with other districts, such as the Catskill mountains. The writer offers the following hypothesis to account for this condition. Fairchild[3] pictures a vast ring of ice completely surrounding the Adirondacks, isolating them from the rest of the State. It was during this stage that the glacial lakes herein described existed. The great ice sheet undoubtedly destroyed all vegetable life in both the Adirondacks and the Catskills, but in the latter case the ice retreated northward as an irregular edge which allowed vegetable life to follow the ice in its withdrawal. This condition was not possible in the Adirondacks where the ice ring prevented much if any encroachment on the part of plants into the ice deforested area. In the Catskill region the glacial drift was anchored by the roots of newly growing shrubs etc., and thus it was not easily washed by the streams into the standing waters in the valleys below, so that a large amount of the drift still remains on the slopes. On the contrary the glacial débris in the Adirondacks was not anchored and most of it has been carried down into the valley bottoms and there worked over into lake deposits. This has an important bearing upon the flora of the region and the disastrous effects of forest fires on the thinly soil-mantled mountain slopes.

Summary of the Glacial Lake Succession

The Mount Marcy quadrangle was situated near the northeast rim of the ring of ice that surrounded and isolated the Adirondack highlands from the rest of the State, and thus the northward-draining valleys were blocked, preventing the escape of the vast quantities of waters which flooded the district with lakes. These bodies of water, especially at the higher levels, did not leave distinct shore line features, for their outlets were controlled by ice lobes which caused constant or periodic lowering of their surfaces.

The district covered by the glacial lakes here described can be divided into two sections, the western and the eastern. In all probability the western section was the first to be relieved of ice, thus

[1] Cushing, H. P., N. Y. State Mus. Bul. 115, p. 495.
[2] Ogilvie, L. H., Jour. Geol., 10:397–412. 1902.
[3] Fairchild, H. L., N. Y. State Mus. Bul. 160, pl. 11.

giving birth to the *South Meadows Lake*. The uncovering of lower outlets to the west extinguished this lake which was succeeded by *Upper Lake Newman*. During this stage the ice lobe that lay in the East branch of the Ausable, eastern section, retreated to allow the *Keene lake* to form, with its drainage to the south. A further lowering of the waters caused a separation of the Boreas-Elk-Clear pond region from the major portion of the Keene lake, which continued to exist as a separate unit. A further subdivision brought about several smaller glacial lakes in the Schroon Lake quadrangle. The continued withdrawal of the ice lobe uncovered the Wilmington notch and thus the Keene lake fell to the level of Upper Newman; bringing about a union of the two sections. Succeeding Upper Newman, *Lower Newman* held the stage until the withdrawal of the lobe in the Elizabethtown-Pleasant valley opened the side outlet channels in the center of the Ausable sheet, when the *Saranac glacial waters* held dominion, draining east. During the lower stages the western section was drained and only the eastern section was flooded.

The *Wilmington lake,* drained through the Gulf; and the *Upper Jay lake,* both Upper and Lower phases, likewise drained to the east. The lakes that succeeded the Upper Jay lakes did not cover any portion of the Mount Marcy quadrangle and are not described in detail.

The nature of the postlacustrine uptilting, which inclined the shore lines of the lakes northward, points to the conclusion that the land was experiencing uplift and warping *while* the ice was retreating from the region. The total amount of uplift since glacial times for the quadrangle may have been greater than 600 feet.

INDEX


Brook
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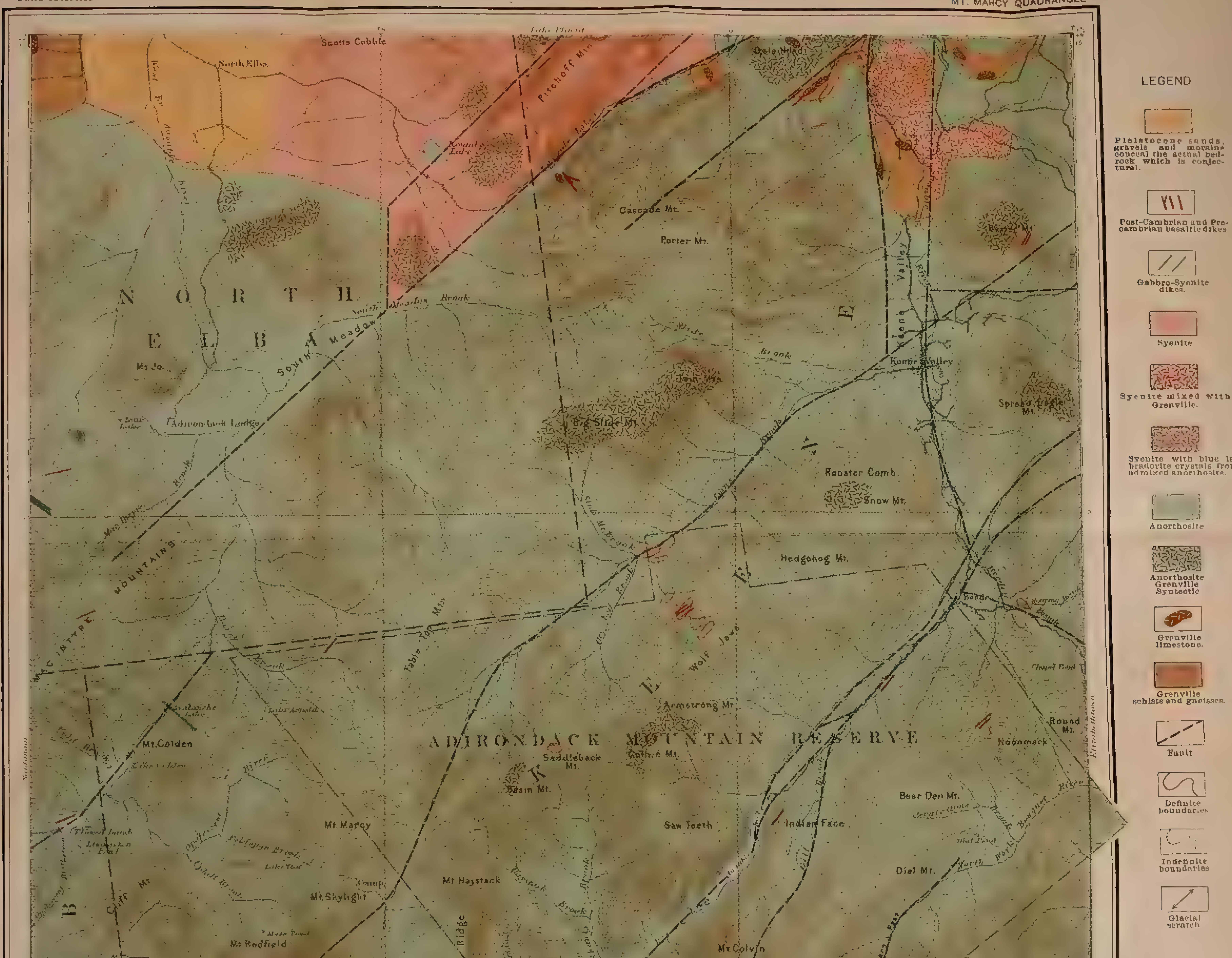
EDUCATION DEPARTMENT
JOHN M CLARKE
STATE GEOLOGIST

UNIVERSITY OF THE STATE OF NEW YORK
STATE MUSEUM

BULLETIN [redacted] 229-30
MT. MARCY QUADRANGLE



Henry Gannett, Chief Topographer.
H. M. Wilson, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by E. C. Barnard and J. H. Jennings.
Surveyed in 1891-92 in cooperation with the State of New York.

Scale $\frac{1}{62500}$

Contour interval 20 feet.
Datum is mean sea level.

Geology by James F. Kemp

Charles H. Fulton
Harold L. Alling } Assistants